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Conservation Decisions: Designing, Financing and Fundraising for Protected Areas

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To the Graduate Council:

I am submitting herewith a dissertation written by Rachel Elizabeth Fovargue entitled "Conservation Decisions: Designing, Financing and Fundraising for Protected Areas." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology and Evolutionary Biology.

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Conservation Decisions: Designing, Financing and Fundraising for Protected Areas

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ABSTRACT

Establishing protection for conservation is a complicated process that involves many critical decisions, from spatial prioritization to garnering the necessary financial support to complete a project. In my research, I address questions that inform various components of this process. First, I ask questions about protected area design using a case study of a large reef system in Australia. I find that simple design rules can facilitate the pursuit of conservation and extractive management goals. Second, I address questions about costs incurred by the financing of new protection. I establish a unique dataset of projects financed by a conservation non-profit through an internal revolving loan. Using this loan data, I examine correlates of loan default which impacts both the long-term success of the defaulted conservation land deal, and the ability of that organization to pursue future land acquisition deals. Last, I partner with a large conservation non-profit to identify predictors of philanthropic giving to the organization. By investigating a finely resolved national dataset, I reveal several correlates of conservation giving, and identify regions where new fundraising techniques could greatly augment available resources for conservation action.

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INTRODUCTION

Protection as a Tool for Conservation

Biodiversity is declining globally and the current extinction rate is estimated to be 100-1000 times background extinction rates (Butchart *et al.* 2010; Barnosky *et al.* 2011; Ceballos *et al.* 2015; McCallum 2015). A major driver of these losses is the conversion and degradation of habitat as well as overexploitation of resources (McLellan *et al.* 2014). On land, urbanization and agriculture are substantial anthropogenic causes of this destruction (Polasky *et al.* 2008; Sachs *et al.* 2009) while in the sea, overfishing and destructive fishing practices contribute to major population declines (Jackson *et al.* 2001). The establishment of protected areas where extractive use and development is limited through spatial regulation continues to be one of the key methods for combating the loss of biodiversity (Margules & Pressey 2000; Sarkar *et al.* 2006; Joppa & Pfaff 2009). Current rates of protection put the international community on target to reach global goals for protected area coverage by 2020; unfortunately, more specific biodiversity objectives still lag far behind desired targets, indicating that more strategic protection is still needed (Juffe-Bignoli *et al.* 2014; Tittensor *et al.* 2014).

The general definition of protected areas agreed upon by the International Union for Conservation of Nature (IUCN), the World Commission on Protected Areas, and the Convention on Biological Diversity describes a protected area as “a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural value” (Borrini-Feyerabend *et al.* 2013; Juffe-Bignoli *et al.* 2014). For my use of the term “protected area” in this dissertation, I will defer to this definition. Within this larger characterization, organizations often further classify protected areas. For instance, globally, the IUCN uses management and governance type as two methods to subcategorize protected areas (Dudley 2008; Borrini-Feyerabend *et al.* 2013). These include categories ranging from scientific reserve to world heritage site. In the United

States, the U.S. Geological Survey's Protected Area Database assigns GAP status codes, which describe levels of protection ranging from "1", land managed to mimic natural ecosystems and regimes, to "4", currently unprotected or unmanaged. These categorization systems demonstrate the variation in interpretations that protected area can take. For example. GAP status code level 3 falls outside the management categories for the IUCN because these lands allow some extractive uses and degradation even though land is still protected from conversion. Regardless of the semantics, marine and terrestrial protected areas are universally used as a tool to prevent or slow the deterioration of natural areas due to land conversion, such as tilling, energy development or urbanization, as well as destructive harvesting practices, such as trawling, clear cutting or poaching (UNEP-WCMC and IUCN 2016).

In the marine realm, large gains in protection have been made in recent years with over 260 million hectares of new protected areas being established between 2014 and 2016 (UNEP-WCMC and IUCN 2016). Marine environments, particularly coastal habitats, are highly impacted by human pressures (Halpern *et al.* 2008) and are worsening with time (Tittensor *et al.* 2014). Protected areas can help mitigate these stresses, and successful population recoveries have been observed across a variety of regions and species where exploitation is prohibited (Moland *et al.* 2013; Guidetti *et al.* 2014). Marine protected areas (MPAs) are particularly successful in supporting fish populations when they are large and isolated with well-enforced regulations (Edgar *et al.* 2014). However, many MPAs lack enough funding to implement effective management and enforcement (Gill *et al.* 2017). Consequently, the global MPA network still falls short of performance goals, and strategic planning techniques should be pursued moving forward (Agardy, di Sciara & Christie 2011).

On land, the primary strategies for protection are land acquisition and easements (Rissman *et al.* 2007; Fishburn *et al.* 2009a). Over 100 million hectares of terrestrial habitat and inland waters have been added to the World Database on Protected Areas since 2010 (Juffe-Bignoli *et al.* 2014). Public lands have long served as a foundation for the protection of natural resources and biodiversity (Loomis 2002). However, historically some of these lands were established in an *ad hoc* manner, thereby diminishing the function they provide to certain biodiversity groups (Pressey 1994). In some countries, private land trusts play an increasingly prevalent role in filling the gaps left by protection in public land systems through new land acquisition (Albers & Ando 2003; Merenlender *et al.* 2004). As of 2017, 372 certified land trusts in the U.S. protect over 20 million hectares of conservation lands (Land Trust Accreditation Commission 2017). Local and national land trusts make regular decisions regarding land acquisition (Merenlender *et al.* 2004; Larson, Boyer & Armsworth 2014). Private land conservation organizations strive to be effective in their decision-making and have demonstrated strategic behaviors in land protection (Fishburn *et al.* 2009b; Fisher & Dills 2012). With the increase in size and cost of land acquisitions, deals have become more complex, often requiring partnerships between organizations and financing plans to cover upfront costs (Ginn 2005; McBryde, Stein & Clark 2005). Combined with increasing costs, limited funding for conservation makes finding sources or tools to support conservation actions even more important.

Key Components and Challenges of Establishing Protected Areas

1. *Where to protect?*

   Through the design of protected areas, planners strive to maximize a variety of ecological and human use benefits. The scientific community has tackled this problem in the conservation planning literature. There exists a substantial history of strategies for the prioritization of areas for protection (Margules, Nicholls & Pressey 1988; Wilson *et al.* 2006; Withey *et al.* 2012). This literature discusses how best to provide adequate area and connectivity of protected areas for biodiversity. Within a single management plan, human food and resource needs are frequently balanced against biodiversity habitat and resource needs (Polasky *et al.* 2008; Goldstein *et al.* 2012). In Boxes 1 & 2, I outline examples of protected area establishment motivated by habitat and connectivity priorities.

Conservation planning has recently ventured in a number of directions focusing on dynamics and uncertainty (Costello & Polasky 2004; Naidoo *et al.* 2006; Pressey *et al.* 2007; Wilson, Carwardine & Possingham 2009). One prominent trend is considering uncertainty around the performance of protected areas. Examples include planning with consideration of future climate change or fluctuating population dynamics through time, which could change the conservation benefits offered by protecting different areas of land or sea (Halpern *et al.* 2006; Ando & Mallory 2012).

2. *When to protect?*

Another key problem addressed in the scientific literature is uncertainty around the feasibility of establishing protected areas through time. In marine settings, political climate often determines when new regulations may create protected areas, as is the case in Box 2. In terrestrial settings, parcels come onto the land market in a somewhat unpredictable pattern, and may only sometimes have a willing seller, as the example in Box 1 (Knight *et al.* 2011). This can lead to a “spend or wait” decision on the part of conservation organizations. Various studies have examined how opportunistic conservation organizations should be about acquiring available land (Drechsler & Wätzold 2007; McDonald-Madden *et al.* 2008). Additionally, there is uncertainty in the availability of funds through time (Costello & Polasky 2004; Drechsler & Wätzold 2007; Larson, Boyer & Armsworth 2014). It may be difficult for conservation organizations to adopt ‘optimal’ acquisition strategies put forward by science if their available capital fluctuates greatly (Prendergast, Quinn & Lawton 1999). Taking loans for land acquisition is a solution to this timing constraint (McBryde, Stein & Clark 2005; Clark 2007). Unfortunately, the current literature fails to capture this common behavior of conservation organizations and rarely considers costs incurred by financing strategies.

3. *How to fund protection?*

Enacting MPAs is a complicated process that requires years of cooperation and investment by governmental and nongovernmental groups. Initiation often requires

Box 1. Story of Conservation: A Land Protection Example

The Ozark Regional Land Trust acquired a 688-hectare property, Woods Prairie, in southwest Missouri in 1999. (Thomas & Galbraith 2003)

1. **Where to protect?**

   Large intact prairies such as the one protected here are a critical component of large scale planning and connectivity in the region as determined by the Gulf Coastal Plains and Ozarks LCC (Gulf Coastal Plains & Ozarks Landscape Conservation Cooperative 2013). This never-plowed remnant is a rare ecosystem, and provides critical habitat to many species of concern including migratory grassland birds, such as the greater prairie chicken (*Tympanuchus cupido)*. Management allows for grazing on some portions to help keep down invasive weeds. This allows a balance of human uses and conservation gains.

2. **When to protect?**

   This purchase was a big investment for a small organization. However, if ORLT did not acquire the parcel, it would likely be converted to agricultural land. They used seller financing options to pay for the property through time with future income.

3. **How to fund it?**

   A fundraising campaign was rapidly started to help pay for the principal of the loan for the property. The land trust asked for both simple donations as well as interest free loans from private individuals. By appealing to local residents, ORLT was able to quickly raise $18,000 to put towards the purchase, and stewardship fund for the future management of Woods Prairie.

Box 2. Story of Conservation: A Marine Protection Example

The United Kingdom has established a network of new marine and coastal protected areas over the last decade. Areas targeting marine habitat and species are termed Marine Conservation Zones (MCZs). One such MCZ, Offshore Brighton, established 86200 hectares of protected area in January 2016 (Eustice 2016).

4. **Where to protect?**

   Offshore Brighton MCZ protects deep channel habitat along the midline of the English Channel. The benthic habitat there is diverse with a variety of marine worm, starfish and clam species. Public comment periods and international stakeholder meetings conducted early in the design process allowed for creation of the MCZs with consideration of human economic and cultural uses. In the case of Offshore Brighton, boundaries were carefully drawn to not overlap with a scallop harvest area to the south used by French fishermen and another high traffic fishing area to the east shared by UK and Belgium fleets.

5. **When to protect?**

   The establishment of the MCZs in the UK was inspired by the international conventions (Convention on Biological Diversity and Convention for the Protection of the Marine Environment of the North-east Atlantic). To reach contribution 2020 targets set by these conventions, The UK will continue to grow its marine protected. Two of a planned three rounds of legislation have been completed, protecting 60 individual MCZs. Offshore Brighton MCZ was part of the second round of legislation approved in 2016.

6. **How to fund it?**

   Since marine protection boundaries are a legislative determination, no cash allotment is required for purchasing protection; however, political capital and government funding for the research and planning is required. In this case, international obligations spurred the political motivation. Additionally, planning institutions consider opportunity costs of local economic uses in the design of potential MCZs.

political support, but MPA creation may use significant public funds over the course of the establishment process (McCrea-Strub *et al.* 2011). Alternatively, land protection, often requiring ownership, is a costly upfront investment. Many land protection projects are becoming larger and more expensive (Davies, Kareiva & Armsworth 2010). Past land protection has been criticized for occurring unsystematically where areas of little value for agriculture or timber, such as steep or dry areas, are left undeveloped (Joppa & Pfaff 2009). Current land protection actions are subsequently often encouraged in areas of high threat of development or conversion (Pressey 1994; Carter *et al.* 2014). The higher market value of these lands makes these parcels expensive. Consequently, expanding resources for conservation is a critical endeavor. Philanthropic donations account for a large portion of non-profit conservation organizations' budgets (Guidestar USA Inc. 2016) and provides a key source of income for protection projects (Box 1). The current literature falls short in describing the spatial patterns of conservation donations and the demographics associated with these patterns.

Dissertation Outline

In this dissertation, I examine three questions advancing the frontier of current protected area science. One question comes from the marine environment where population dynamics of target species are particularly important and much protection is done through regulatory action. Two questions examine terrestrial protected areas, and focus on the role that private land trusts play in growing the protected area network. In contrast to most marine settings, establishing protected areas on land often requires paying to acquire property rights. Therefore, for these two chapters I focus on questions tied to the emerging field of conservation finance.

In Chapter 1, I investigate questions about MPA design. I focus on how relatively simple policies perform in the presence of uncertainty about complicated spatio-temporal population dynamics of target species. I use a model of reef fish population dynamics in the Great Barrier Reef to address questions about the usefulness of size and spacing rules for protected areas. In particular, I aim to explore how data-limited regions may benefit from design rules tested on a well-studied system using simulation models with stochastic dispersal regimes. I find that design rules are able to balance conservation and fishery management goals under various scenarios of protection.

With my research in Chapters 2 and 3, I transition to questions of land protection. In doing so, I collaborated with The Nature Conservancy (TNC) to use their rich history of land protection across the continental U.S. As the largest land trust in the world, TNC serves as an ideal case study organization for exploring questions regarding the finances of land acquisition. They have been actively protecting land in the US since 1955 and for decades have cultivated donors and implemented a revolving fund to help finance new projects within the organization (Birchard 2005; Kareiva, Groves & Marvier 2014).

In Chapter 2, I focus on the financing of land purchases. Using loans to create capital for projects can be risky because of uncertainty around the ability to achieve a timely loan repayment. If a land trust could better understand factors that increased the risk of having a loan go long in repayment, then the organization could potentially avoid larger-than-expected costs. Given this, I ask: "What characteristics of a land acquisition deal predict delayed loan repayments or large interest payments?" I demonstrate that there are large loan financing costs involved that must be accounted for when prioritizing different areas for protection.

Chapter 3 addresses spatial patterns of fundraising for land protection. Increased financial support is critical to future conservation efforts and land trusts often look to the local communities to help support new land acquisitions (Clark 2009). Better understanding of philanthropic giving to conservation may aid organizations to augment funding. In Chapter 3, I use fundraising data provided at a fine spatial grain from TNC to reveal patterns in philanthropic giving. I identify sociodemographic and other characteristics of a locality that help to predict the propensity and scale of giving across the conterminous U.S. Characteristics of a location such as educational attainment levels rise to the top as highly predictive of giving. I also use this statistical model to illustrate how a conservation organization could use this analytical approach to inform fundraising efforts and discuss its implications for identifying areas for future protection.

In my dissertation conclusion chapter, I summarize my research by revisiting this introduction's general questions for establishing protected areas: When to protect? Where to protect? And how to fund it? Additionally, I provide synthesis and discussion of Chapters 1-3 on several topics including challenges of decision making under trade-off scenarios, the advantage of flexibility in policy and planning, as well as enabling factors and benefits of scaling up conservation efforts.

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CHAPTER 1

SIZE AND SPACING RULES CAN BALANCE CONSERVATION AND FISHERY MANAGEMENT OBJECTIVES FOR MARINE PROTECTED AREAS

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Abstract

1. Marine protected areas (MPAs) are increasingly integrated into fishery management for coastal systems. Size and spacing rules (SSRs) have been proposed as simple MPA design guidelines, especially in regions where population connectivity data are limited.
2. I assessed whether SSRs allow managers to design effective MPA networks under spatiotemporally varying dispersal patterns using a spatially realistic population model parameterized for a commercially-exploited fish species on the Great Barrier Reef.
3. SSRs are used to design MPA networks, and population simulations are used to measure the mean and variance of the resulting population size and fishery catch.
4. I show that SSR performance is contingent on the extent of the MPA network, and whether species' connectivity data can be used to target areas for protection. For example, in the absence of connectivity data, a 'many small' MPAs rule provides the least variable management outcome.
5. *Synthesis and applications*. I demonstrate that the performance of SSRs depend on the level of knowledge about larval dispersal, as well as the level of current exploitation in the fishery. These context-dependent results offer particularly relevant guidance to future MPA design projects in regions with limited connectivity data.

Introduction

Marine protected areas (MPAs) have become a key component of conservation and fishery management for near-shore ecosystems (Allison, Lubchenco & Carr 1998; Lester *et al.* 2009; Banks & Skilleter 2010). Connectivity patterns that link locations of adult fish spawning to offspring recruitment help determine whether the spatial configuration of an MPA network can achieve management objectives (Botsford, Micheli & Hastings 2003; Costello & Polasky 2008; White *et al.* 2014). However, measuring connectivity in coastal systems is notoriously difficult (Jones *et al.* 2009; Cowen & Sponaugle 2009). In regions where this data may be unavailable or difficult to incorporate, MPA planning is based on general rules for the size of individual MPAs and the space between them (hereafter referred to as "size and spacing rules"; SSRs). SSRs offer straightforward guidance for network design (Hastings & Botsford 1999; Green *et al.* 2014), and suggest that MPAs of particular average size, with particular average spacing between them, can deliver both conservation and fisheries goals. Thus, to be useful, an SSR would need to generally produce superior or more consistent outcomes than alternate SSRs for fisheries management and/or conservation.

SSRs have long been studied with theoretical models, and suggestions arising from this literature are used to inform real-world MPA design (Sala *et al.* 2002; Gleason *et al.* 2010; Fernandes *et al.* 2012). Models are particularly useful for working on spatial and temporal scales where experimentation is infeasible. Additionally, in places of high uncertainty, model predictions can help to direct future empirical research to resolve key uncertainties, perhaps in a value of information setting or as a base-line for adaptive management (McDonald-Madden et al. 2010; Runge et al. 2011). Many theoretical models indicate that conservation and fishery goals require different MPA configurations, resulting in management trade-offs (Kaplan & Botsford 2005; Gaines *et al.* 2010). Theory and some empirical studies have shown that fisheries outcomes are maximized when MPAs are split into small pieces (thereby maximizing spillover). In contrast, the conservation goal of larger populations is best achieved by consolidating MPAs into large continuous areas (Collins *et al.* 2002; Hastings & Botsford 2003; Claudet *et al.* 2008).

SSR studies cited by real-world MPA design, while providing useful guidelines, include some simplifying assumptions that could impact their performance in real-world applications. The population models analyzed are often spatially implicit (Nowlis & Roberts 1999; Hastings & Botsford 1999; Mangel 2000) or use simple patch models or one-dimensional linear models to represent coastlines (Hastings & Botsford 2003; Halpern *et al.* 2006; Kaplan *et al.* 2009; Pelc *et al.* 2010; Moffitt, White & Botsford 2011). MPA design studies often use symmetric dispersal kernels or simple advection models to represent larval dispersal, and these remain constant through time (Lockwood et al. 2002; Kaplan & Botsford 2005; Halpern et al. 2006; White et al. 2010b; Guizien et al. 2012). Yet larval connectivity patterns are driven by highly-variable oceanographic drivers, and are therefore characterized by spatial and temporal heterogeneity (McConnaughey *et al.* 1994; James *et al.* 2002; Harrison *et al.* 2012). This variability is likely to impact the performance and reliability of different SSRs.

I therefore re-examine the performance of alternative SSRs using a spatially-explicit population model that includes this heterogeneity. My model is parameterized for a reef fish species on Australia's Great Barrier Reef (GBR). However, in many parts of the world, these connectivity patterns are poorly understood, and collecting better data on dispersal is prohibitively expensive (Sale *et al.* 2005; Burgess *et al.* 2014). The resulting uncertainty makes it difficult to configure an MPA network that achieves fishery and conservation objectives (Botsford *et al.* 2009). One of the strengths of SSRs is their applicability in the absence of explicit data on dispersal, but managers still need to understand which SSR is expected to best deliver management goals. My relatively data-rich case study of the GBR provides an opportunity to model the performance of different MPA configurations. By ignoring knowledge of underlying dynamics when designing an MPA network, I mimic a data-deficient system and can thereby explore consequences of applying SSRs in systems where connectivity data are less available. Specifically, I create many test MPA configurations through SSRs and use simulation models to evaluate the efficacy of these hypothetical MPA networks.

I explore how the efficacy of different SSRs varies with two factors: the MPA network extent, and managers' ability to use dispersal data in MPA design. Since exploitation levels have been identified as a guiding consideration in MPA design and success, the contrasting dynamics of over- and under-exploited fisheries may necessitate different design rules for a network (Kaplan *et al.* 2009; Costello *et al.* 2010; Gaines *et al.* 2010). By varying access to fishing in my model, I can investigate the SSR performance under a variety of protection levels. Though still rare, connectivity information is valuable for designing MPA networks and can improve configuration performance ((Sale *et al.* 2005; Costello *et al.* 2010; Rassweiler, Costello & Siegel 2012; Lester *et al.* 2013). I explore how dispersal knowledge level impacts the usefulness of SSRs by comparing scenarios that use no dispersal information in MPA placement with scenarios that have a greater capacity to pick high-performing configurations.

In this paper, I test SSRs as guidelines for management of near-shore marine systems by using simulation models with realistic patterns of variation in dispersal. Particular SSRs are useful if they can increase the likelihood of achieving above average or predictable management. This leads me to ask if a SSR provides (1) larger fish catch, (2) larger wild population size, or (3) lower variance outcomes. By observing covariation in fishery and conservation goals, I reveal the context dependency of scenarios where these outcomes are opposing or synergistic.

Methods

I begin by defining SSRs for heterogeneous marine systems. Spacing rules define the average distance between any two neighboring MPAs. Likewise, size rules regulate the average size of each MPA within the network. Size and spacing are often considered as independent factors, but are necessarily codependent for a given MPA network extent (Fig. 1.4). For example, if 10% of the total reef area is protected, and if the each MPA is set to be 1% of total reef area, then there can be only 10 MPAs, and the average distance between them is subsequently more constrained. For a set total area, the network configurations can range across a spectrum from many small MPAs with a short spacing distance, to a few large MPAs with longer average spacing distances (Fig. 1.1).

Designing MPAs with SSRs

To compare SSRs as guidelines for MPA network design, I created and simulated a wide variety of MPA network configurations. A spacing distance (in degrees) and a fixed total network area (km^2) subsequently determined average MPA size. When there were N distinct MPAs in the network, each had approximate size (*Total area protected*)/N. I chose the site of each MPA by selecting a latitudinal point at random and building the MPA outwards from there, sequentially adding the closest unprotected reefs until the desired size was reached. Each treatment group (combination of total network extent and SSR) included 200 MPA configurations. In the Discussion, I place these SSRs into a broader comparison with other rules reflecting real-world interpretations.

Population model and case study

To assess the conservation and fisheries outcomes of each configuration, I used a population model loosely parameterized for coral trout (*Plectropomus leopardus*, Serranidae), a commercially exploited species on the GBR that is a priority for management (Leigh et al. 2014; see Supplemental Materials 2 for life cycle details). My model tracked 13 age classes at each of 2165 discrete reef locations. Reef habitats are patchily distributed, and adults of most reef fish species remain closely associated with the reefs on which they settle at the end of a pelagic larval stage (Samoilys 1997; Jones *et al.* 2009; Planes, Jones & Thorrold 2009). Dispersal was assumed to occur only during the larval stage and upon settlement, larvae attempting to enter the recruiting cohort experience density dependent mortality following a Beverton-Holt relationship (Bode *et al*. 2016). Dispersal patterns were stored in seven annual connectivity matrices, generated by a detailed model of larval dispersal that is based on plausible assumptions about coral trout life history, including pelagic larval duration and larval swimming capabilities (James *et al.* 2002; Bode *et al.* 2012). Physical forcing in the model was based on a high-resolution oceanographic model, calibrated using available current and wind data in the GBR.

Variable dispersal was simulated by drawing randomly each time step from the available matrices, each representing an annually averaged connectivity between each pair of reefs spanning the entire GBR (for years 1996-2002). This population dynamic model was overlaid with a fishing model that assumes a fixed proportion of biomass on unprotected reefs is annually harvested.

Each MPA configuration was tested using the same model parameters. At the end of a 400-year model run, the fishery and conservation performance of the configuration was evaluated by averaging over the last 50 time steps. By this time, dynamics reach a steady-state around which values stochastically fluctuate due to the time-varying dispersal. The respective performance measures were the average annual catch (metric tonnes), and the average abundance of fish remaining on the reef (number of adults). All simulations and analysis were completed using a commercial software package with population dynamics code provided as Supplemental Materials 2 (MATLAB 9.0, 2016, The MathWorks Inc., Natick, Mass, United States)

Analysis

To reveal general patterns across SSRs, I tested three distinct SSRs: ‘many small’, ‘intermediate’, and ‘few large’. When applied, these rules respectively had average spacing distances of 0.2, 2.1, and 4.0 latitudinal degrees, thereby creating 76, 7, and 3 protected areas in each configuration. Previous SSR studies often made recommendations based on ‘average dispersal distance’ of managed species. A frequent recommendation is that the inter-MPA distance be twice the average dispersal distance (Halpern et al. 2006; Lockwood et al. 2002; Palumbi 2003; Shanks et al. 2003). Although average dispersal is hard to estimate in my system due to the highly asymmetric dispersal kernels, the median distance travelled by the simulated larvae is 110 km (approximately one latitudinal degree). My ‘intermediate’ rule therefore approximates this common ‘twice dispersal distance’ rule. A larger set of SSRs did not expand my conclusions, a point I return to in the Discussion and provide results for additional examples in the SI.

Level of protection

In spatially managed fisheries, harvests are controlled by both the amount of space open to fishing and the effort level allowed in the fishable areas. The total area protected (MPA network extent) strongly influences the performance of the MPA, regardless of the configuration of the network (Claudet *et al.* 2008). In my study, I only control the level of exploitation by varying the MPA network extent, with a constant effort level on unprotected areas. Consequently, the amount of area protected is inversely related to exploitation (Mangel 1998, 2000; Hastings & Botsford 1999). To see how this coverage interacts with spacing rules, I created MPA configurations that covered 10%, 20%, 30%, and 40% of the total reef area. These protection levels encompass the size of no take MPAs currently present in the GBR (Great Barrier Reef Marine Park Authority 2005). This results in a total of 12 treatment groups (3 SSRs; 4 levels of protection).

Knowledge level

I first configured MPA networks with the assumption that managers were entirely uninformed about larval dispersal patterns and their effect on important locations for MPAs. I then assessed how information on larval dispersal would improve network performance by separately analyzing results from the best performing MPA configurations within each treatment group, on the assumption that connectivity information would allow managers to identify better networks. The top 10% from each group were chosen by normalizing and giving equal weight to both outcome metrics. This provided a set of near-dispersal-optimal solutions. Narrowing to identify the single best solution for a given SSR is infeasible due to the large set of potential networks, and lengthy run-time required for each candidate network. However, I show that this *post hoc* estimation is a sufficient way to approximate the management outcomes of near optimal performances in the appendix (Fig 1.7). I will refer to the full set of configurations as 'dispersal uninformed' and the top 10% subset as the 'informed' scenario.

Visualization

Each MPA configuration evaluated with the simulation model has two associated success metrics, fishery catch and abundance. Therefore, a configuration can be plotted as a point (arrow, Fig 1.3A) in two-dimensional objective space. All 200 configurations from the same treatment group can be plotted in the same way (cloud of points, Fig 1.3A). This reveals the variable performance of different MPA configurations that share an SSR and protection level. In Fig. 1.3A, this uncertainty is visually summarized by a crosshatch, displaying the median, 1st and 3rd quartiles. Following a single color (a single SSR) horizontally across the plot, shows how protection level changes performance. I compare SSRs by observing a single shape grouping.

Statistical tests

The predicted catch and abundance are characterized by skew and by pronounced heteroscedasticity. To address my questions about differences in the average trend for outcomes, I bootstrapped my performance results and tracked the median for both fishery catch and abundance. I report 95% confidence intervals on these values; non-overlapping CIs are stated as differences in median outcomes for different SSRs, which provide a relatively conservative test for differentiation (Efron 1987). Similarly, to address my questions about differences in the variance for outcomes under alternate SSRs, I bootstrapped my data and tracked the 1st and 3rd quartiles for both catch and abundance. I calculated the difference between these values (i.e., the 1-3 interquartile range) and report 95% confidence intervals on this difference. Non-overlapping CIs are stated as differences in the variance of SSRs. This procedure was applied to both the informed and uninformed scenarios.

Results

No single SSR is the optimal choice across scenarios. Instead, the best of the three general rules tested is contingent on both the level of protection (network extent and harvest proportion) as well as the knowledge level, or managers' ability to identify and target advantageous locations using dispersal information (Table 1.1; Fig. 1.3). The following sections show how the choices of rule and information level affect my desirable outcomes: (1) high fishery catch, (2) high population abundance, and (3) low variance. I additionally describe patterns of covariation in these outcomes. Fig. 1.3 shows the covariance in measured objectives of all tested MPA configurations. The median values plotted are reported in Appendix A with bootstrapped 95% CI.

Fishery objective

To address whether a particular SSR produces high catches, I compare spacing rules within a set percent coverage. For 'dispersal uninformed' scenarios, figure 1.3A shows that the catch generated does not vary between SSRs at lower levels of protection (10-20% of GBR protected). However, as the network extent increases (30-40% protected) the 'many small' spacing rules generate clearly the highest median catches (non-overlapping 95% CI of the median, Table 1.2). The 'informed' networks contrast these results (Fig 1.3B). With a low level of protection (10%), 'few large' is statistically superior to the alternative rules (Table 1.2), generating fishery outcomes that are 8% larger than the 'many small' rule. At mid-range levels of protection (20-30%) SSRs show few substantive differences in fishery outcomes; however, at high levels of protection, 'many small' gives fishery catch 11% higher than the 'few large' rule (Table 1.2).

Conservation objective

By again comparing SSRs within a coverage group, I address my second question: Does one SSR perform best for fish population abundance? For 'dispersal uninformed' scenarios, almost none of the SSRs generate significantly larger fish abundances. The exception is the 'few large' rule at 30% protection, which outperforms the other rules (Fig. 1.3A). In other words, in the absence of information on connectivity patterns, SSRs cannot guarantee an abundance that is higher than random expectation (overlapping 95% CI, Table 1.3). The 'informed' MPA networks present a dramatically different result (Fig. 1.3B). Across all levels of protection assessed, the 'few large' rule provides a consistently higher fish abundance, between 11% and 23% higher than the 'many small' rule (Table 1.3)

Consistency in objective

The distance between 1st to 3rd quartile values of each treatment group measures the extent to which SSRs may provide consistent management outcomes. Comparing this difference value within a coverage group reveals patterns in variance across SSRs. For all 'dispersal uninformed' coverage scenarios, the 'many small' spacing rule exhibits lower variance than other spacing rules. This is true for both fishery catch and abundance outcomes. In contrast, no differences in variance are observed in the 'informed' scenario (Table 1.4 & Table 1.5).

Covariation of objectives

Each spacing rule, applied to a range of different levels of protection, produces a unique pattern of covariation between catch and abundance. In Fig. 1.3 this can be seen by following a single pacing rule (e.g. 'many small') from 10% to 40% coverage levels. As the level of protection increases, abundance increases monotonically but fishery catch increases and then decreases. This result mirrors the predictions of theoretical models (Mangel 2000; White et al. 2010a; Lester et al. 2013). For more on this pattern, see Fig. 1.5.

These covariance relationships resemble those that determine a maximum sustainable fishery catch. For each SSR, this peak in the catch-abundance curve can be achieved at a particular level of protection. For example, the location of this maximum catch is near 30% protection for the 'intermediate' rule (Fig. 1.6). Overall, this increasing-decreasing fishery catch pattern holds across all spacing rules in both 'dispersal uninformed' and 'informed' scenarios; however,
the dimensions of the curves vary among spacing rules. For example, the maximum catch point shifts from 40% for a 'many small' spacing rule to near 25% for the 'few large' spacing rule (Fig. 1.6).

Discussion

Designing networks of near-shore marine protected areas is a challenging task (Botsford, Micheli & Hastings 2003; Banks & Skilleter 2010). Simple rules about the size and spacing of network MPAs have been proposed as heuristic methods for incorporating dynamics of larval dispersal, even in the absence of such information. Though results from simple theoretical models support this approach, it is important to assess whether these results hold in a more realistic system. Here, I explore whether general SSRs aid MPA design by using a data-rich case study of a single-species on the GBR. I found that among SSRs tested, some generate consistently superior results, but rule selection varies with the level of protection, as well as the level at which connectivity information is used to target top configurations.

The effectiveness of SSRs depends heavily on the total extent of MPA network. When the fishery is overexploited, it is most effectively improved by boosting standing fish population – a win-win scenario. So, following a SSR that increases population also increases fishery outcomes (left hand column, Table 1.1). Among my low protection 'dispersal uninformed' MPAs, no rule provides markedly better outcomes; however, as the ability to choose high-performing configurations improves ('informed' scenario), well-placed clustered MPAs most effectively improve population size, and thus fishery catch. As higher protection decreases fishable areas and boosts fish populations, a 'many small' rule consistently demonstrates higher fishery catch compared to other spacing rules, through spillover from protected to fished areas (right-hand column, Table 1.1). Therefore, when population levels are healthy and resilient, splitting up MPAs into small segments helps to maximize the fishery output. My results reinforce the recognized influence of exploitation levels on marine planning and SSR performance (Quinn, Wing & Botsford 1993; Kaplan *et al.* 2009; Gaines *et al.* 2010).

Managers' understanding of larval dispersal patterns and ability to respond to these patterns through spatial targeting can affect the performance of SSRs. Many regions globally do not have information on larval connectivity, despite its value to spatial management.

Further, in complex systems, multi-species management with social, economic and political constraints hinder the ability to exclusively use dispersal patterns for MPA design providing another setting in which generalized SSRs may be useful (Roberts *et al.* 2003 Nardi *et al.* 2004; Smith *et al.* 2010; Moffitt, White & Botsford 2011; White *et al.* 2013). For a successful design and implementation process, stakeholder groups across a wide range of values and interests, from recreational users to traditional use fishermen need to be consulted and their needs considered against biological ones. (Klein *et al.* 2008). Recent examples of this process have been documented for the California Marine Life Protection Act (Gleason *et al.* 2010) and the United Kingdom's Marine Conservation Zone (Ashworth et al. 2010, MAIA 2011). When SSRs configure MPA networks without employing knowledge of underlying connectivity patterns, only the 'many small' rule is useful, since it lowers the variability of management outcomes, and sometimes improving fishery catch (top row, Table 1.1). Conversely, when examining the best performing MPA networks ('informed' scenario), conservation benefits and trade-offs appear among different rules (bottom row, Table 1.1). Contiguous MPAs can increase both fishery catch and standing biomass under low levels of protection. When the fishery is better protected, there is a trade-off in rules reflecting theoretical expectations (Hastings & Botsford 2003; Kaplan & Botsford 2005; Gaines *et al.* 2010). Therefore, if knowledge about connectivity can be used to identify and target important regions for protection, it may be beneficial to cluster protection in key areas, creating fewer, larger MPAs (Mace & Morgan 2006; Carter *et al.* 2014).

Finally, my model illustrates how heterogeneity in reef location and dispersal patterns creates variation in management outcomes among alternate MPA networks. However, I show the possibility to reduce this variance among alternative configurations with a 'many small' rule. In real management scenarios with limited knowledge and a high level of uncertainty, reducing variance in performance could be a central goal (Halpern *et al.* 2006). Generally, I present results as a risk neutral decision-maker, by comparing median performances to maximize the expected result. However, broad variation in potential outcomes allows for diverse interpretations according to risk preferences. A risk-adverse designer might compare the worst outcomes in each SSR and select the one that minimizes chances of negative outcomes. Alternatively, a risk-tolerant designer may compare best outcomes under each SSR (much like my 'informed' scenario). As knowledge about the system is resolved, variation in management outcomes is reduced (Fig. 1.3B), meaning the choices that would be recommended across a range of risk preferences become more similar. A clear example of risk trade-offs can be seen in the 'uninformed' 10% coverage catch performance. Here, the 'many small' SSR's lack of bad outcomes make it a strong choice for risk-averse decision-makers while top performances under 'few large' attract risk-tolerant designers. So, although median management outcomes are indistinguishable among SSRs, differences in variation may still inform MPA design.

Further assumptions of human behavior and interpretation may also impact my findings. Here I highlight those addressed with sensitivity analysis or suggested for extension work. First, results may be contingent on the method I used to choose MPA configurations, or my interpretation of 'spacing rule'. Accordingly, I explored alternative placement mechanisms that imposed stricter spatial stratifications to ensure my random placement of MPAs was not strongly skewing my results (Table 1.7). Moreover, I examined a more complete range of spacing distances. Many real-world SSR recommendations suggest a best spacing distance, but all spacing distances tested fell along the same continuum drawn by my three core SSRs (many small, intermediate, and few large). For example, configurations with a SSR 'median dispersal distance' (110 km) perform between the 'many small' and 'intermediate' outcomes (Fig 1.8). Using habitat type to specify the distribution of MPAs is another possible interpretation of MPA spacing (Fernandes *et al*. 2012). I compared my outcomes against a spacing method that uses 31 defined bioregions in the GBR to configure MPAs (Great Barrier Reef Marine Park Authority 2005). This 'bioregional' rule performs better than or equal to my spacing rules in terms of fishery catch and performs almost as well as the 'few large' rule in maintaining a large fish abundance (Fig 1.8). Here, extra information about habitat delineations is incorporated into the design process, and like better dispersal knowledge, improved performance of resulting MPAs.

To allow MPA size to represent over- to under-exploited scenarios (Stelzenmüller *et al.* 2008;), my simple representation of fishing pressure ignores displacement. The use of a displacement (Smith & Wilen 2003) or spatially-explicit fishing model (Lester *et al.* 2013) would be a logical extension of this work. Extensions could also consider other costs and policy implications related to MPA configuration type. A variety of issues arise as protected areas become smaller and less clustered. (Roberts *et al.* 2003). Accessibility for fishing and recreation may be more difficult, and dispersed MPAs require greater enforcement effort (Kritzer 2004; Davis *et al.* 2015). Alternatively, a few large MPAs could have disproportionate spatial impacts on fishing communities (Halpern *et al.* 2013). Such additional social costs will affect the relative benefits of the different SSRs.

My study also made many biological and environmental assumptions. First, my model incorporates stochasticity only in the dispersal dynamics, but uncertainty, heterogeneity, and stochasticity exist across the entire ecosystem. For example, although I test a design rule using bioregional definitions, uncertainty exists in habitat type delineation which may strongly impact MPA design (Tulloch *et al*. 2013). Exploring stochasticity in the survival and growth parameters in the population dynamics would allow for exploration of MPA configuration resilience to catastrophic events. This may be an important extension as consideration of catastrophes has been shown to change the extent and design of near-shore MPAs (Allison *et al*. 2003; Game *et al*. 2008). Nevertheless, I performed a sensitivity analysis of the main parameters controlling my population dynamic model. Results of these sensitivity analyses did not change qualitative patterns (Table 1.6).

In conclusion, SSRs can provide information relevant to MPA network design, but the performance of different rules is contingent on a range of factors, principally the state of the fishery, and managers' ability to identify important areas based on dispersal patterns. Real-world variation in success of MPA networks (Lester *et al.* 2009; Gaines *et al.* 2010) may be influenced by the interacting effects of fishery state and design capability. Regardless, I show that variance in performance in MPA outcomes can be reduced by adopting a 'many small' MPA strategy. These results should be considered when managers are developing new near-shore MPA networks especially when limited in their knowledge about or ability to respond to connectivity patterns.

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Appendix 1: Tables

Table 1.1 Key results for MPA design scenarios

		Protection Level	
		Low 10%, 20%	**High** 30%, 40%
Knowledge Level	**Dispersal Uninformed**	**Little difference** *Rarely a spacing rule performs better for fishery catch or abundance*	**‘Many small’** *A ‘many small’ spacing rule performs better for median fishery catch*
	Dispersal Informed	**‘Few large’** *A ‘few large’ spacing rule performs better for median fishery catch and abundance*	**Trade-off** *A ‘many small’ spacing rule performs better for fishery catch; a ‘few large’ rule performs better for abundance*

Table 1.2 Confidence intervals of median fishery catch

To quantify differences in median catch values, each treatment group sample is bootstrapped for its median catch value. Listed are the 95% confidence intervals (lower/median/upper) for the bootstrapped median values of fishery catch (thousand tonnes). Results are highlighted in bold when the 95% CI do not overlap between spacing rules.

			Protection Level			
			10%	20%	30%	40%
Knowledge Level	Dispersal uninformed	Many Small	**5.1/5.2/5.3**	**6.1/6.3/6.4**	**6.7/6.8/7.0**	**6.9/7.0/7.1**
		Intermediate	4.3/4.5/4.6	5.5/5.9/6.1	**6.0/6.2/6.4**	**5.5/5.7/6.0**
		Few Large	4.3/4.6/5.0	5.0/5.5/5.8	**5.2/5.5/5.8**	**5.0/5.3/5.5**
	Informed	Many Small	6.1/6.2/6.4	**7.1/7.2/7.4**	7.8/7.9/8.0	**7.9/8.0/8.2**
		Intermediate	6.2/6.4/6.5	7.7/7.9/8.1	7.9/8.1/8.2	7.3/7.4/7.7
		Few Large	**6.5/6.7/7.0**	7.5/7.7/8.0	7.1/7.5/8.1	6.4/7.2/7.6

Table 1.3 Confidence intervals of median abundance

To quantify differences in median abundance values, each treatment group sample is bootstrapped for the median abundance value. Listed are the 95% confidence intervals (lower/median/upper) for the bootstrapped median values of adult abundance (millions of fish). Results are highlighted in bold when the 95% CI do not overlap between spacing rules.

			Protection Level			
			10%	20%	30%	40%
Knowledge Level	Dispersal uninformed	Many Small	124/126/129	179/181/185	239/242/244	295/299/305
		Intermediate	**107/111/117**	175/183/192	231/240/250	290/300/307
		Few Large	115/124/131	183/191/202	**253/264/277**	304/321/335
	Informed	Many Small	149/152/157	**210/212/220**	**273/279/283**	**330/333/339**
		Intermediate	149/154/160	**233/240/245**	**286/298/313**	362/366/373
		Few Large	**174/181/184**	**256/261/271**	**335/341/357**	360/371/397

Table 1.4 Confidence intervals of fishery catch variance magnitude

To quantify differences in variance of recorded catch in alternate treatment groups, the sample is bootstrapped for the 1st and 3rd quartile values. Listed are the 95% confidence intervals (lower/median/upper) for the difference between the bootstrapped 1st and 3rd quartile values. This difference (75th percentile – 25th percentile) corresponds to the magnitude of the variance in the values of fishery catch (thousand tonnes). Results are highlighted in bold when the 95% CI do not overlap between spacing rules.

			Protection Level			
			10%	20%	30%	40%
Knowledge Level	Dispersal uninformed	Many Small	0.64/0.82/0.96	**0.78/0.95/1.14**	**0.78/0.93/1.09**	**0.74/0.94/1.16**
		Intermediate	0.92/1.20/1.41	1.63/2.01/2.33	**1.34/1.63/1.99**	1.39/1.79/2.25
		Few Large	**1.67/1.99/2.22**	2.26/2.60/2.83	**2.13/2.48/2.85**	1.71/2.05/2.41
	Informed	Many Small	0.15/0.36/0.61	0.24/0.54/0.89	0.18/0.35/0.51	0.22/0.43/0.68
		Intermediate	0.18/0.41/0.68	0.31/0.57/0.98	0.17/0.69/1.12	0.24/0.59/0.77
		Few Large	0.35/0.87/1.75	0.36/0.85/1.59	0.68/1.15/1.49	**0.94/1.48/2.01**

Table 1.5 Confidence intervals of abundance variance magnitude

To quantify differences in variance of recorded abundance in alternate treatment groups, the sample is bootstrapped for the 1^{st} and 3^{rd} quartile values. Listed are the 95% confidence intervals (lower/median/upper) for the difference between the bootstrapped 1^{st} and 3^{rd} quartile values. This difference (75^{th} percentile – 25^{th} percentile) corresponds to the magnitude of the variance in the values of adult abundance (millions of fish). Results are highlighted in bold when the 95% CI do not overlap between spacing rules.

			Protection Level			
			10%	20%	30%	40%
Knowledge Level	Dispersal uninformed	Many Small	**20.0/22.9/26.1**	**20.1/24.9/28.7**	**23.6/29.0/34.3**	**28.1/32.8/37.2**
		Intermediate	**26.8/33.3/38.4**	50.9/58.6/67.5	**50.2/58.7/68.4**	61.6/74.3/86.7
		Few Large	**45.0/52.4/60.7**	59.9/72.5/84.1	**72.1/84.2/101**	71.8/81.1/90.4
	Informed	Many Small	6.4/12.4/16.7	4.92/11.6/20.1	**6.91/14.0/22.6**	6.65/20.3/34.3
		Intermediate	8.3/13.0/18.7	7.95/15.6/30.0	22.8/36.6/49.7	8.87/20.3/34.3
		Few Large	9.6/18.0/29.0	10.1/20.8/37.1	12.4/27.7/50.6	25.9/50.7/77.3

Table 1.6 Sensitivity of population model parameters

To examine how uncertainty in the population dynamics model affects my conclusions, I repeated the entire analysis shifting key parameters. Simulations were run under the following scenarios: Beverton-Holt α at 50% decrease (0.008) and 50% increase (0.024), fishing mortality at 50% decrease (0.035) and 50% increase (0.105). All other parameters were held at original values. New results are compared to the key findings from main text highlighted in bold when similar. Most results are not qualitatively sensitive to these shifts in parameters. The variance outcomes are most stable result.

	Low Protection Levels		*High Protection Levels*		*Variance*	
	Dispersal Uninformed	Informed	Dispersal Uninformed	Informed	Dispersal Uninformed	Informed
Main Text Results	**No Difference between Rules**	**'Few Large' for Fishery Catch and Abundance**	**'Many Small' for Fishery Catch**	**Trade-off: 'Many Small' for Fishery Catch, 'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**
Alpha 20% Increase	'Many Small' for Fishery Catch;	**'Few Large' for Abundance**	**'Many Small' for Fishery Catch**	**'Many Small' for Fishery Catch;**	**'Many Small' lowest**	**Little Difference**
Alpha 20% Decrease	**No Difference between Rules**	**'Few Large' for Abundance**	Trade-off: **'Many Small' for Fishery Catch**, 'Few Large' for Abundance	**'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**
Mort 20% Increase	**No Difference between Rules**	**'Few Large' for Fishery Catch and Abundance**	Trade-off: **'Many Small' for Fishery Catch**, 'Few Large' for Abundance	**Trade-off: 'Many Small' for Fishery Catch, 'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**
Mort 20% Decrease	'Many Small' for Fishery Catch;	**'Few Large' for Fishery Catch and Abundance**	**'Many Small' for Fishery Catch**	**Trade-off: 'Many Small' for Fishery Catch, 'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**

Table 1.7 Qualitative results sensitivity to spacing strictness

I sought to examine the effects of using alternate MPA configuration selection methods. First, the complete analysis was repeated using the two methods that increase the strictness of spacing in the MPA siting step. I examined qualitative differences between these results and the original main text results (Table 1). Results that remain similar are highlighted in bold. Most results are not qualitatively sensitive to these shifts in methods. The variance outcomes are most stable out of any measured results.

Latitudinal Binning

The total area to be protected and the spacing rule (in degree distance) determine the number and size of individual MPAs. The entire GBR is then stratified into latitudinal bins. Each bin contains an equal number of reefs, and there are as many bins as protected areas to be created. MPAs are then created by drawing a reef randomly from within a bin and building subsequently outward, adding nearest reefs until the desired MPA size is achieved.

Even Latitudinal Spacing

The total area to be protected and the spacing rule (in degree distance) still determine the number and size of individual MPAs. However, equidistant latitudinal lines, numbering the same as number of MPAs and spaced at the chosen spacing rule are laid across the entire GBR. MPAs are then created by selecting the reef closest to each line and building subsequently outward, adding nearest reefs until the desired MPA size is achieved.

	Low Protection Levels		*High Protection Levels*		*Variance*	
	Dispersal Uninformed	Informed	Dispersal Uninformed	Informed	Dispersal Uninformed	Informed
Main Text Results	**Little Difference between Rules**	**'Few Large' for Fishery Catch and Abundance**	**'Many Small' for Fishery Catch**	**Trade-off: 'Many Small' for Fishery Catch, 'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**
Latitudinal Binning	**Little Difference between Rules**	**'Few Large' for Fishery Catch and Abundance**	**'Many Small' for Fishery Catch**	**'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**
Even Latitudinal Spacing	**Little Difference between Rules**	**'Few Large' for Fishery Catch and Abundance**	'Intermediate' for Abundance	**'Few Large' for Abundance**	**'Many Small' lowest**	**Little Difference**

Appendix 2: Figures

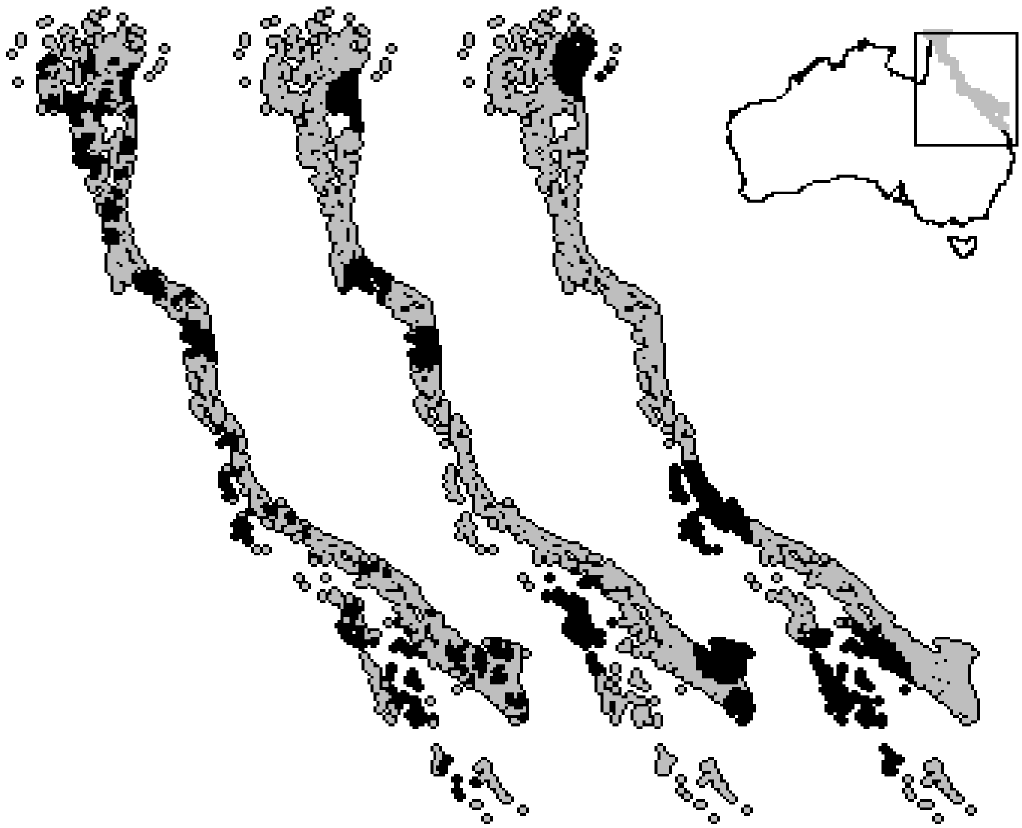

Figure 1.1 Example MPA network configurations

SSRs: ‘many small’, ‘intermediate’, ‘few large’ (left to right). Markers indicates a single patch reef; black markers denote reefs protected under these example configurations. Inset: Reef location along Australian coastline.

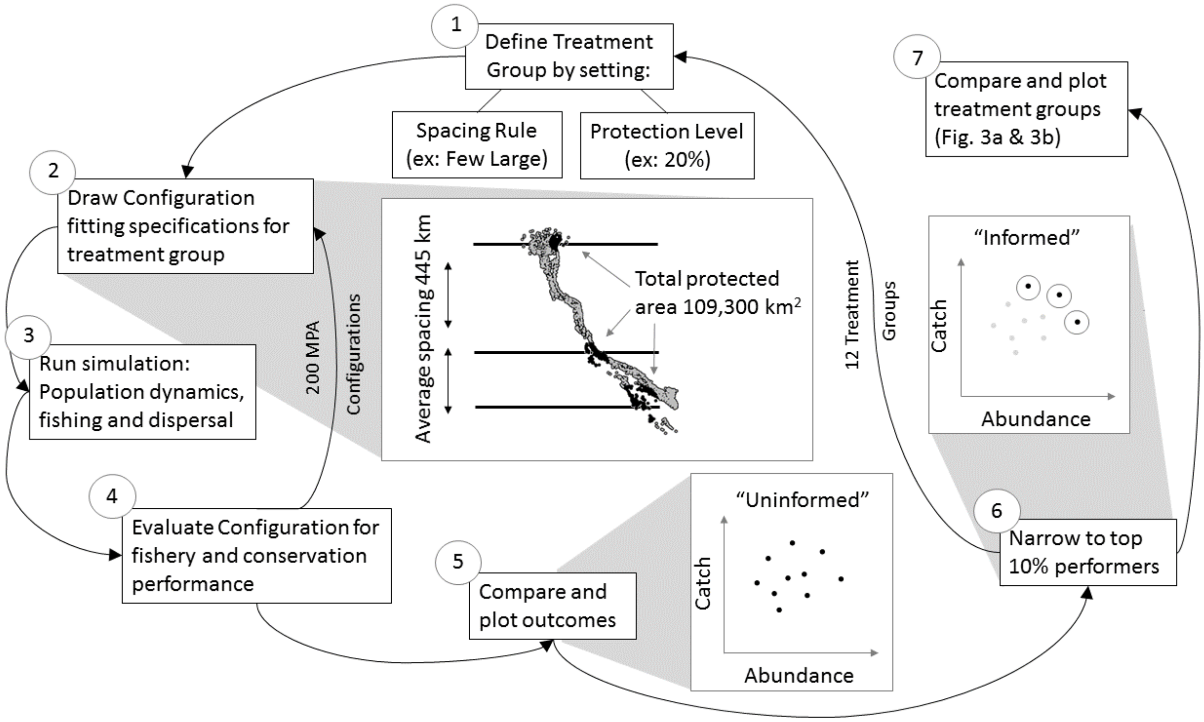

Figure 1.2 Walk-through of MPA configuration creation and analysis.

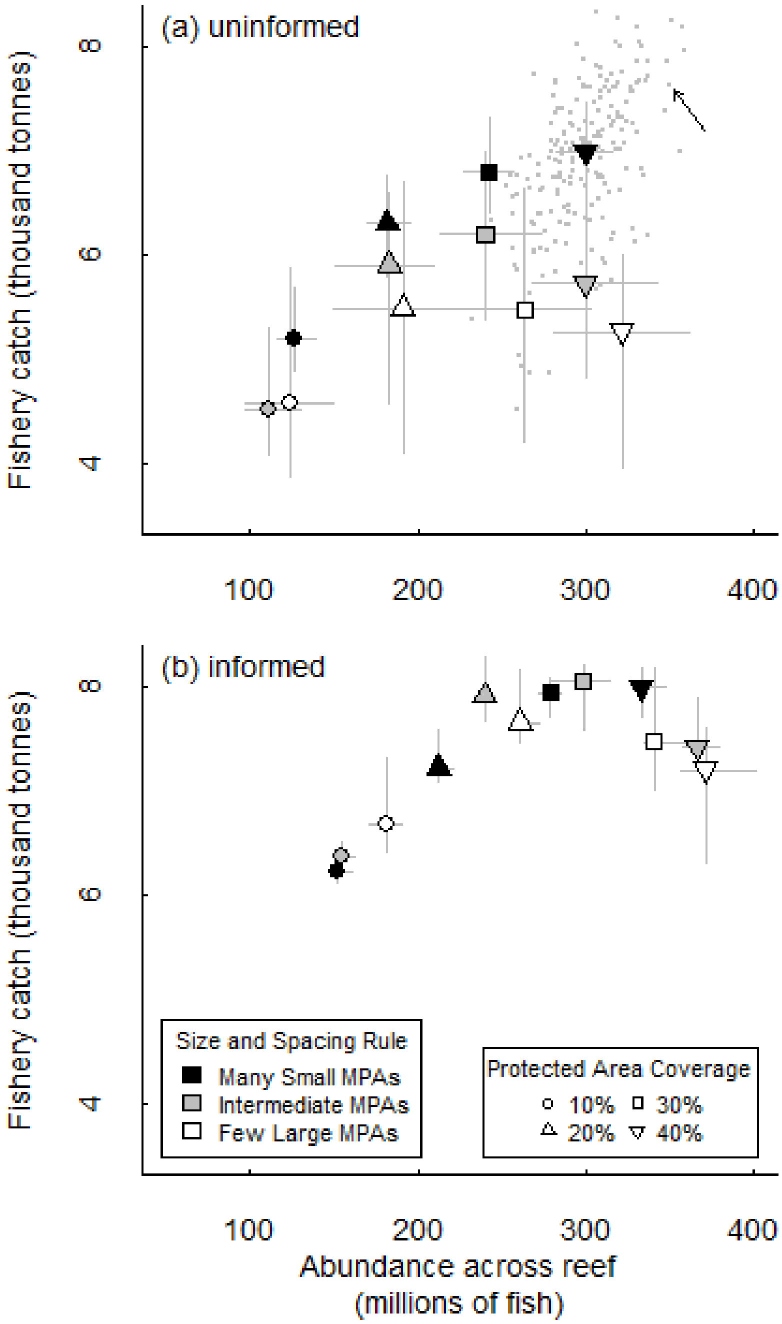

Figure 1.3 Covariation of A) dispersal uninformed and B) informed configurations. The 12 treatment groups are shown (Spacing rules: ‘Many small’, ‘intermediate’, and ‘few large’; Proportion protected: 10%, 20%, 30%, and 40%). Each treatment group median is plotted with 1st and 3rd quartiles grey lines. A sample of configuration outcomes for the ‘Many small’/40% treatment group are plotted as grey points.

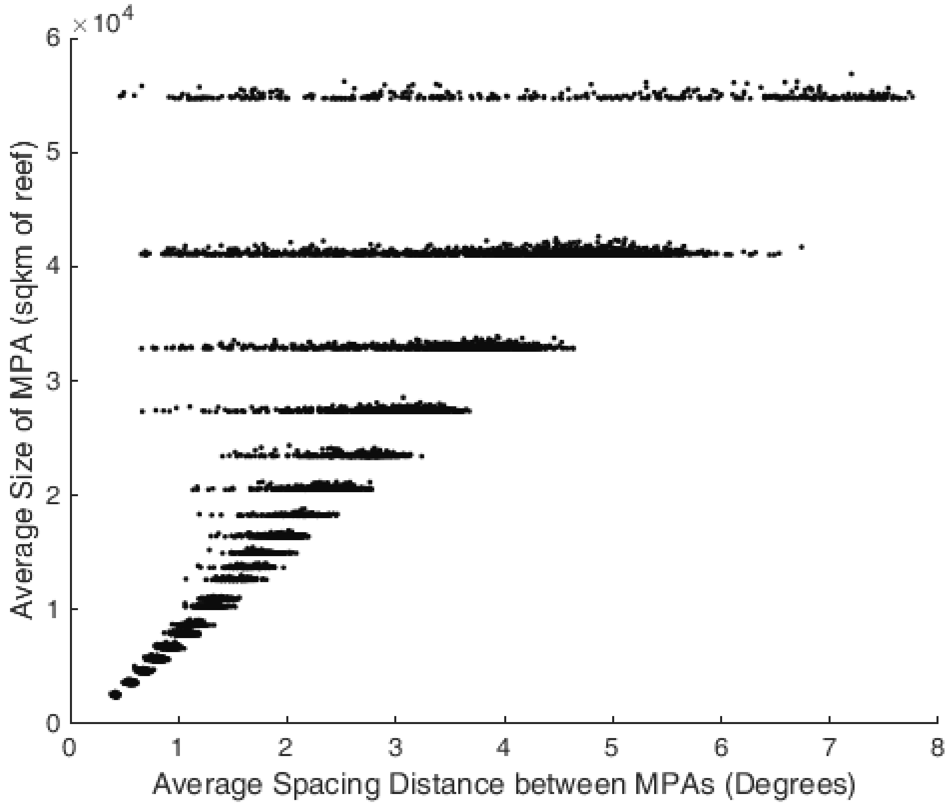

Figure 1.4 Covariation in size and spacing

Covariation between the size and spacing of protected areas in an MPA configuration. MPA configurations protecting 20% of GBR area are shown. Each configuration has a set number of equally sized protected areas which have been drawn randomly in regards to space. For each configuration, the average size of its protected areas and average space between protected areas are determined and plotted as a point. Average spacing is determined by drawing a minimum spanning tree across MPAs in the configuration and reporting the mean edge distance. This figure demonstrates that in systems in finite space, there is inevitably a positive relationship between the size of MPAs and the average distance between them. As MPAs become smaller and more numerous, they naturally become closer together.

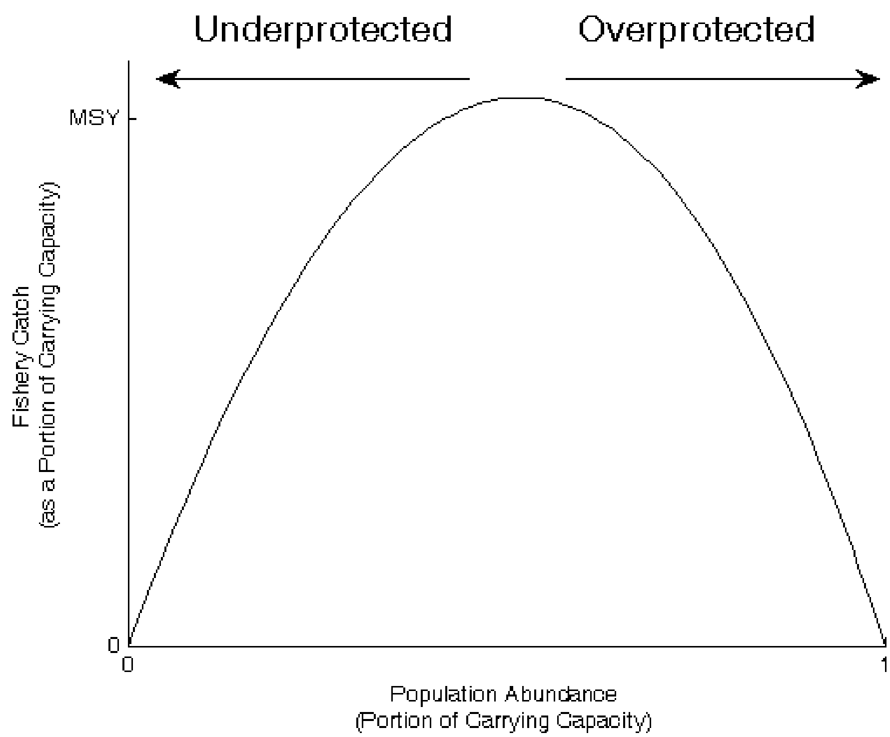

Figure 1.5 Covariation in abundance and catch (idealized)

Idealized catch-abundance curve for spatially controlled fishery where fishing effort is controlled by the total area under protection. This parabolic curve is revealed by varying the proportion protected and plotting the steady state for fishery catch versus population abundance. No protection leads to fishery collapse, with population and catch at zero. Full protection has zero catch with population at carrying capacity. It is easy to interpret the peak of the curve as analogous to a Maximum Sustainable Effort from other harvest models. To the left of that point is ‘under-protected’, because adding protection would increase yield; to the right is ‘over-protected’, because opening more places to fishing increases the steady-state yield. This catch-abundance parabola is mirrored by my results in Fig. 2 of the main text.

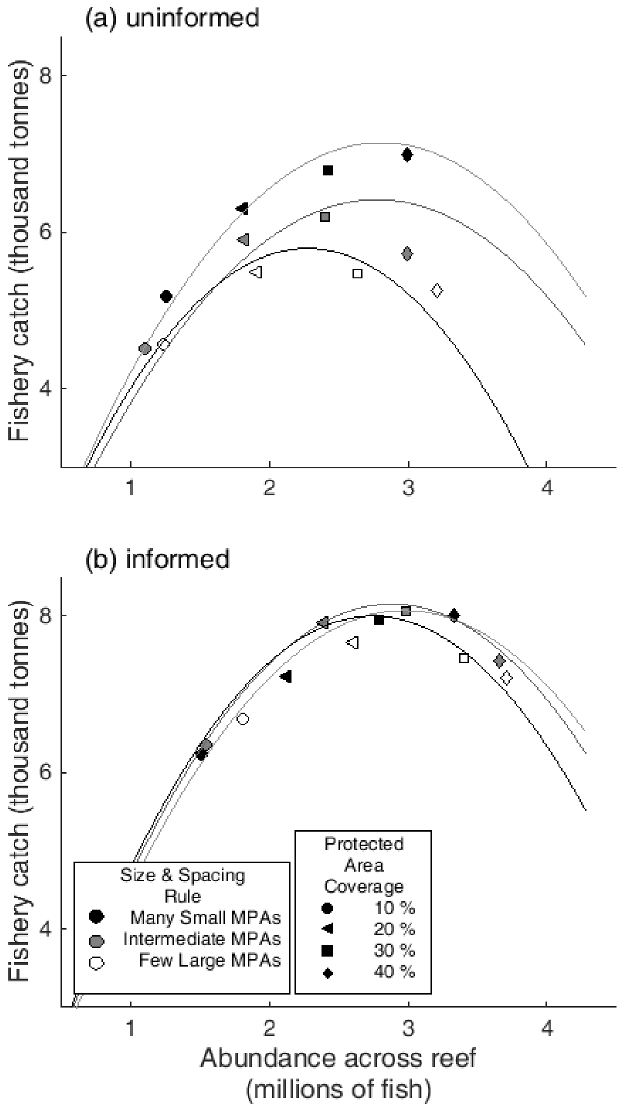

Figure 1.6 Covariation in abundance and catch (Realized in model)

Catch-abundance parabolas are fitted for each size and spacing rule. These parabolas are shown here with the main results in Figure 2a and 2b. The parabolas are fitted to the raw data (800 configurations for each rule) for both the (A) 'dispersal uninformed' and the (B) 'informed' scenario results. The median for results from each spacing rule and protection level are also plotted. By tracking the peak of the parabolas across different size and spacing rules, it is clear that dimensions change. Most notably, the peak shifts to the left as rule goes from 'many small' to 'few large' although this pattern is diminished in the 'informed' scenario.

Figure 1.7 Near optimal performance trajectory

Relationship between sampling intensity of MPA configurations and best observed performance among sample. Circles are interpreted as the average performance level of the best performing configuration if N number of configurations were analyzed. Colors represent different protection levels (White is 10% coverage of the GBR, Light grey 20%, Dark grey 30%, and Black 40%). To demonstrate how performance approaches optimal, I created 2000 configurations for each treatment group from the main analysis. For each sampling size (N), I draw N number of configurations from the pool of 2000, then identify the best performance observed in that sample. I repeat this 1000 times for a particular sampling size and plot the median of the best outcomes observed across the 1000 samples. When considering the performance of near-optimal solutions, the choice of performance metrics matters greatly. Here, the key performance metrics are the estimated catch available and the estimated biomass that can be supported. Importantly, as alternative MPA sets meeting a given SSR are evaluated, aggregate performance metrics like these may converge quickly, even though the particular spatial locations being chosen to protect continue to change. In other words, the surface traced by relevant performance metrics may flatten out as the optimal solution is approached. Indeed, I observe exactly this type of dynamic with the model and the diminishing returns in the performance metrics with larger sampling are easily observed. By the time the sampling size gets to 200 (my sample size in the main analysis) the best configurations are similar to more intensive sampling groups. So I define the "dispersal informed" set in my main analysis as the top ten percent of configurations in terms of the win-win performance metric (combined metric described in the main text). Given the diminished returns in increasing sampling across the configuration state space, I acknowledge these as near optimal.

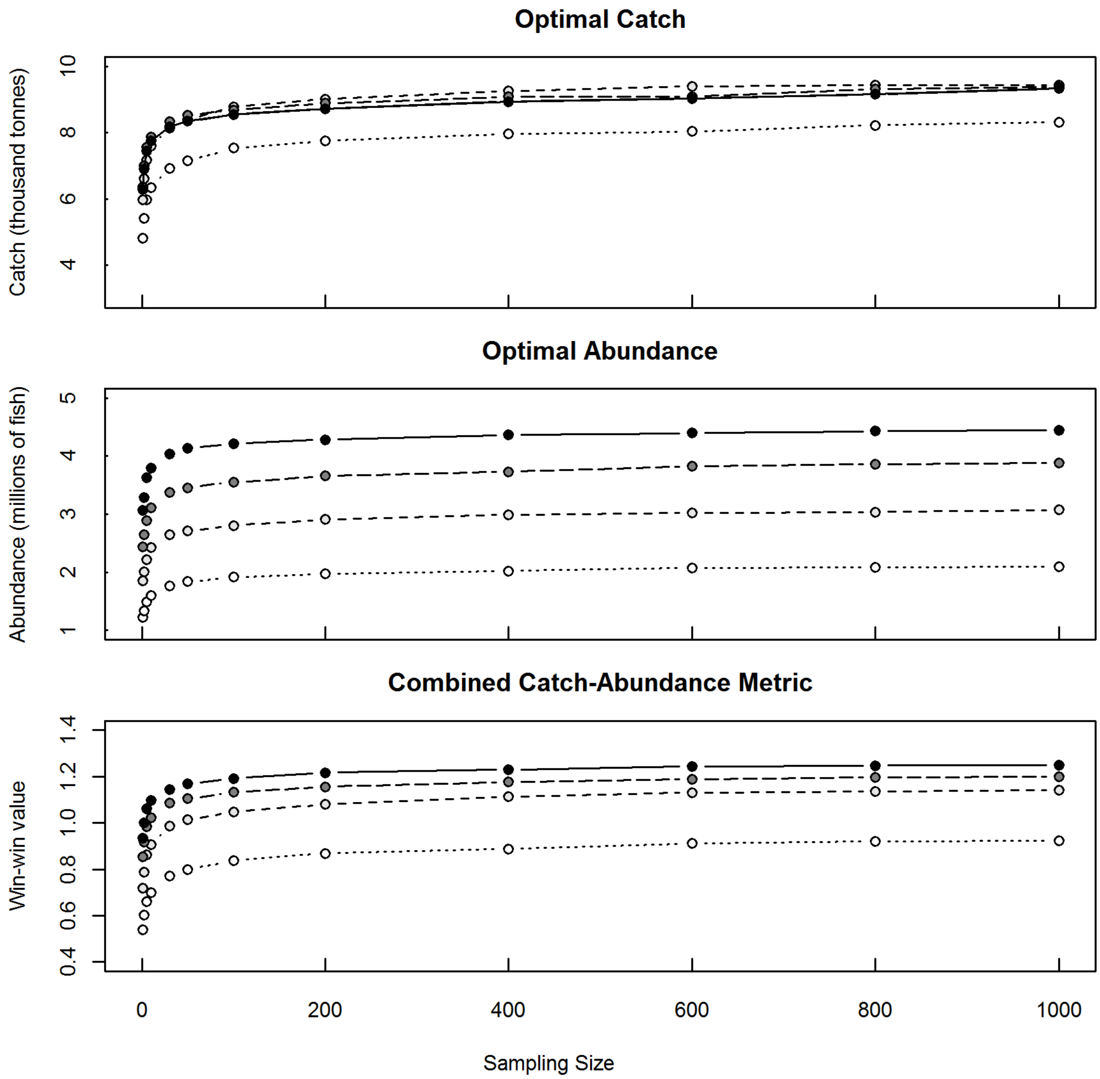

Figure 1.7 Continued

Figure 1.8 Comparative spacing rules

Covariation of 'dispersal uninformed' configurations across 5 spacing rules. The 12 treatment groups described earlier are shown (Spacing rules: 'Many small', 'intermediate', and 'few large'; Proportion protected: 10%, 20%, 30%, and 40%). The median for each treatment group is plotted. Additional spacing rules 'average dispersal distance' and 'bioregional spacing' median performances are plotted across the four protection levels (10%, 20%, 30%, 40%). Two further spacing rules grounded in recommendations are presented in comparison with the main results. I report median values of these other spacing rules across the four protection levels (Tables S7 & S8) and qualitatively compare their outcomes to my original rules

1) 'Average dispersal distance' is configured under the same methodology as main SSRs with average spacing of 110km, an estimated median dispersal distance of the study species from the dispersal model.
2) 'Bioregional spacing' is creating by choosing a starting point at random in each of 31 bioregions, then building out a single MPA composing 10%, 20%, 30% or 40% of the bioregions total area depending on treatment group.

As summarized in the Discussion, the behavior of the 'average dispersal distance' rule falls somewhere between the many small and intermediate SSRs I illustrated. With the added data of bioregional definitions, the 'bioregional spacing' performs better than or equal to the SSRs I focused on for fishery catch and almost as well as the 'few large' SSR for maintaining fish abundance.

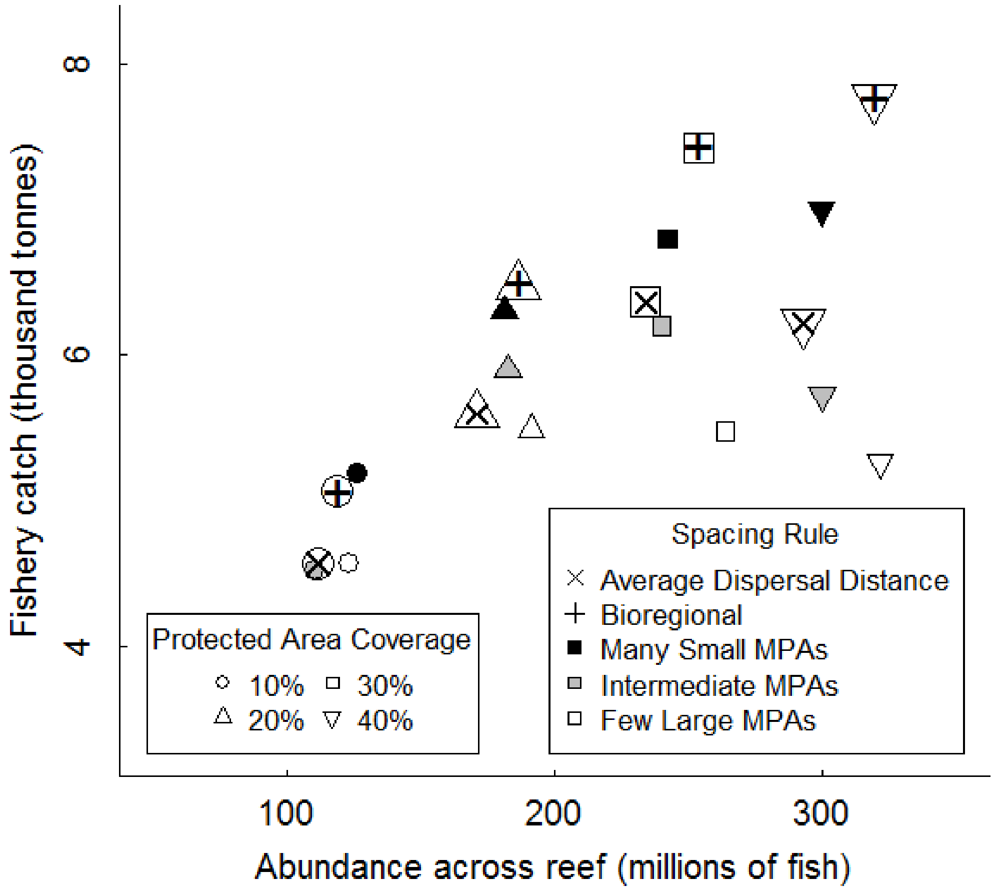

Figure 1.8 Continued

CHAPTER 2

FINANCIAL COSTS OF LAND CONESRVATION

A version of this chapter is being formatted for submission for publication by R. Fovargue, J. Fargione, M. Garrison and P. Armsworth:

Fovargue, RE, J Fargione, M Garrison, PA Armsworth. "Financial Costs of Land Conservation". *Conservation Biology*.

MG & JF supplied key data sets and input into analysis. RF & PA both contributed to the study design, and data interpretation, as well as revisions to the text. RF was primarily responsible for data compilation and analysis and initial drafts of the manuscript.

Abstract

New land protection is expensive and the mismatch through time between opportunities for acquisition and income emphasize the importance of flexible means of purchase. This makes the use of loans a critical tool for conservation, but one rarely discussed in the conservation planning literature. I take a first step toward quantifying this behavior by analyzing the performance of a set of loans supporting land protection through an internal revolving fund at a large US conservation nonprofit. I estimate loan financing cost through accrued interest and propensity of default. I then test deal-level characteristics for explanatory power of these metrics. I demonstrate that loan performance can be highly uncertain, that costs can be substantial in relation to the total purchase price, and provide examples of how this may impact prioritization.

Introduction

Land protection is a critical tool for of conserving biodiversity. Land trusts play a growing role in establishing new conservation lands, often acquiring lands directly, creating easements or facilitating public agencies in taking ownership of new protected areas by serving as temporary land holders (Merenlender *et al.* 2004; Chang 2016). Unfortunately, conservation is chronically underfunded (Shaffer, Scott & Casey 2002; McCarthy *et al.* 2012) and new land purchases are increasingly more expensive, even after accounting for inflation trends (Davies, Kareiva & Armsworth 2010). This funding deficiency is accentuated in situations where a large investment is needed quickly, as is often the case when a property comes on the land market for a short window. If this timing does not coincide with grants or fundraising seasons, then an organization may be caught shorthanded. Preparing for such moments is critical for efficient decisions and action (McDonald-Madden *et al.* 2008). As a result, many land trusts turn to financing options to supply the quick cash infusion that many conservation opportunities need. Taking a loan helps to grant flexibility in paying for a property over time with future income or allow time for a partner organization to prepare to take on the property.

From planning to acquisition and management, land protection is a complicated process that involves uncertainty and careful strategy (Groves & Game 2016). To inform the decisions made by conservation organizations, it is vital that, as a literature, conservation biology recognizes the practical constructs that these organizations work within. Use of loans as an enabling tool for land acquisition is one area that has been rarely mentioned in the conservation science literature (but see Bos, Pressey & Stoeckl 2015; Ando & Shah 2016; Lennox *et al.* 2016). Yet over 50% of land trusts report in a survey conducted by The Conservation Fund as having used financing to assist in purchases (*pers comm.* Amundsen). Not only do traditional loaning agencies, such as banks, provide lending opportunities to conservation groups, but many national and regional conservation organizations manage revolving funds to use explicitly for conservation (Clark 2007). Some, such as The Conservation Fund, the Open Space Institute, and the Maine Coast Heritage Trust, provide external loans (Clark 2007). Other organizations manage internal revolving funds to provide a temporary funding source for their own projects, such as The Nature Conservancy's Land Preservation Fund (Birchard 2005). Though my discussion focuses on U.S organizations, loans for conservation work are seen internationally as a valuable instrument (Keipi 1995; Lennox *et al.* 2016). In this paper, I concentrate on internal revolving loan funds as an example of conservation lending. However, lending programs for habitat conservation are being explored through many mechanisms. For example, a recent interest in conservation has arisen in the impact investment sector. There, individuals and private groups provide loans for habitat conservation with expectation of a small monetary return supplemented by social benefits (Hamrick 2016). I will return to this in the discussion.

Loans are critical as an enabling mechanism to allow for quick action by land protection organizations. In addition to relieving the money-in-hand constraint on conservation action, financing can permit small land trusts to dream bigger. Large-scale reserves which minimize fragmentation and reduce edge effects not only have important ecological benefits (Woodroffe 1998; Peres 2005), but also present cost efficiencies with economies of scale demonstrated across both acquisition and management costs (Armsworth *et al.* 2011; Kim *et al.* 2014). Loan financing allows for these larger, often more complicated plans involving multiple partnerships, to be realized. As land purchases become more expensive, financing to allow bigger projects also becomes more critical. It has been demonstrated that there are particular moments in which a timely allocation of funds can allow for efficient conservation gains (Radeloff *et al.* 2013; Larson, Boyer & Armsworth 2014). Loans allow for this timely investment, and in the case of revolving funds, further allow a single dollar for conservation to be leveraged across many projects by repeat lending through time.

Although providing flexibility to organizations to have greater choice about and ability to pursue potential conservation acquisitions, loans incur added financial cost in terms of interest payments over time. Commitment to debt repayment also incurs an implicit opportunity cost to the borrower because other conservation opportunities may need to be passed over during the repayment period. These drawbacks are both part of a cost benefit trade-off that a land trust considers when financing new projects. There is a further risk of the inability to repay a loan in a timely manner, which impacts both the loaning institute with lower-than-expected returns and the borrower with a potential loss of collateral. Furthermore, both borrowing and lending organizations can become overextended with funds tied to a project that goes long in repayment, which subsequently grows the opportunity cost of the loan decision beyond expected levels. There are many possible circumstances which may cause a loan to be slow to repay. Perhaps a planned resell or transfer of the property falls through, a fundraising campaign does not bring in as much capital as expected, or external circumstances, such as a market crash lowers income to the organization and the value of the property.

An accurate projection of costs and risk is critical for evaluating trade-offs faced by conservation practitioners. To better explore loans as a major funding mechanism for conservation, I take a first step toward evaluating cost and risk of conservation loans and identifying potential project correlates of each. I track land acquisition deals from proposal to repayment within a case study comprising a large land trust with an internal loan fund.

I first aim to investigate how loans impact the cost incurred by a borrowing organization and how this cost may influence decision-making, particularly the prioritization of land deals or the decision to pursue a particular land deal. Specifically, I ask whether known characteristics of a proposed deal or a borrower explain variation in interest accrued over the lifetime of the loan, how interest correlates with the purchase price of a deal, and whether including interest costs changes prioritization rankings of proposed deals.

Next, I consider how loaning organizations, often themselves conservation non-profits, may view these loans and risk they might impart. Specifically, I provide information about what proportion of loans in the dataset were not repaid by the expected date and how much extra time and interest was needed to repay fully. I also ask whether there are characteristics of a deal that explain variation in organizations' propensity to miss the proposed repayment date, or amount of unanticipated interest accrued.

Methods

I use a set of historical land acquisition deals to examine interest accumulation and repayment time on loans for land purchases.

Data

I use records of land acquisition deals by The Nature Conservancy (TNC), which provides internal financing opportunities for state chapters through the Land Preservation Fund (LPF). The LPF was first established in 1979 as a $20 million internal revolving fund, and has since grown significantly (Birchard 2005; Clark 2007). Inside the United States, TNC is structured with state chapters that perform much of the on-the-ground conservation work. The LPF, managed at the TNC national headquarters, provides bridge loans to chapters pursing large land acquisition projects. The use of a case study of a single organization allows me to track projects from proposal stages through loan repayment within the same record-keeping and organizational structure. I extract characteristics of the deal and financial plans from a set of land deals acquired between the years 2000-2011. This decade witnessed a variety of economic conditions, including two recessions followed by periods of economic expansion. In fact, the LPF interest rates tracked these external market conditions, with peak annual interest rates coinciding with high points in United States prime rate (years 2001, 2007, 2008). Therefore, this time period should encapsulate a variety of behaviors for pursuing loans.

Projects selected for the analysis all had purchase prices of at least $1,000,000 and both requested and received a loan account from the LPF. TNC was active throughout this time period, with over a thousand large land deals being approved by the board over the 12 years. Further, I use only projects where I was confident that a single financial transaction could unambiguously be associated with an individual land deal (and so excluding, for example, instances in which a single loan was used to fund a growing set of land acquisitions through time). This selection method censors the dataset in several ways, mainly by excluding land acquisition deals less than $1,000,000 (these did not require the same proposal process, but also likely were in less need of loan financing) and deals that sought outside financing options or did not need financing. By focusing on expensive deals that required internal financing, the selection pool may have a higher propensity for poor loan performance. Contrarily, the dataset is also leaves out deals whose proposed plan sufficiently changed so as not be recognizable in both data sets. These unstable plans may have been of higher risk for loan performance and by censoring these deals, may leave a more conservative group of deals for the analysis.

After matching across data sources, a subset of 181 deals was identified across 24 state chapters (median of 6 loans per state). I extracted characteristics from these deals manually from internal TNC documents that explain why the acquisition was being pursued and provide details for likely funding scenarios (deal characteristics, Table 1). I estimated loan performance metrics from matched accounts (Figure S1). Start date was the observed purchase date in the loan account and repayment date was defined as the first date in which the remaining loan balance fell below 0.1% of the purchase price. Interest accrued for the loan was subsequently defined by any interest charges between these dates. All monetary values are reported in 2010 USD (translated using Consumer Price Index from the Bureau of Labor Statistics).

Describing Loans

I first examine descriptive statistics of loan characteristics both as they were projected at the time of proposal and as they were realized over the time to repayment. Along with this, I address the simple question: does a bigger loan lead to more interest? I estimate a rank correlation for the interest and purchase price of a deal both in the predicted and realized form. This allows me to assess the linkage between interest and price in both the planning stage and implementation stage of a land acquisition deal.

Generalized Linear Mixed Models

I create generalized linear mixed models (GLMMs) to explain loan performance using information that a decision-maker would know ahead of time. Given the sample size (N=181), to prevent overfitting (Harrell 2015) I limit the number of parameters to 9 fixed effects and one random effect chosen *a priori* as the most likely to influence loan performance, identified through conversations with practitioners (*pers comm.* Hall & Amundsen). Specific hypotheses focus on project characteristics such as future land use plans or funds dedicated to the purchase. I also hypothesize that projects with established take-out plans, meaning a strategy in place to resell or transfer the property to a partner organization, are less risky and would accrue less interest. Furthermore, I hypothesize that some characteristics of the borrowing chapter, like average expenditure and income, will also correlate to better loan performance. Additional explanations of *a priori* hypotheses are given in Table 1. Collinearity of predictors was checked using variance inflation factors and fell within tolerated ranges.

First, I look to explain total interest accrued. Given the skewed distribution of interest and presence of zeros, I transformed the raw interest values for use with a Gaussian family (log(TotalInterest+1)). Second, I use a binary variable to indicate whether the loan missed the estimated date of repayment. Third, to take a more nuanced perspective of late repayment, I look at differences between predicted and realized interest. This disparity represents the unanticipated costs of the loan, including additional opportunity costs.

Impact on Prioritization

I tested the impact of loan costs on a return-on-investment framework prioritization using this set of TNC deals. Consideration of loan financing costs within this context may change prioritizations if loan costs are large and not correlated to purchase prices or the other upfront costs more traditionally used for ROI analyses (Boyd, Epanchin-Niell & Siikamäki 2015). I compared rankings of the full set of deals, the first prioritization using only purchase price and the second using purchase price and financial costs (estimated interest). I ranked all projects based on dollar per hectare protected. I report differences between the rankings with and without financial costs by estimating Spearman's Rank Correlation Coefficient.

Results

Loan Performance

Land acquisitions in the dataset ranged from 2010 USD $1 million to 2010 USD $76 million and were strongly right skewed with three quarters of purchase prices falling under 2010 USD $5 million. Most projects protected forested habitat. The median project area was 330 hectares. At the time of writing the project proposal documents, the average acquisition had 7% of the purchase price either in hand or pledged to the project. Some pledged funds covered the full cost of the project, which, if realized, allowed for a quick repayment. About 57% of projects had a take-out plan to resell or transfer the acquired parcel to another agency or organization. Over half of the take-out plans in place at the time of proposal writing were with state government partner organizations.

Across all projects, the median interest accrued per loan was $104,136. When comparing accrued interest to the interest predicted by the project proposal documents, only 16% of loans paid more interest than anticipated; nonetheless, these loans that underestimated interest accumulated on average an additional $163,000. We find that the predicted interest is often estimated with a fixed rate based on the rate offered that fiscal year, but that the loans experience an annually adjusting rate. Because of this uncertainty, many of the proposals show a 'worst case scenario' interest estimate where the full principal remains unpaid for the life of the loan. This behavior helps to explain the frequent over prediction observed. On the opposite end of the spectrum, 17% of projects accrued no interest. These projects either had pledged funding, grants that came in quickly, or a take-out plan completed within the first month of the loan (sometimes in as little as 24 hours), so no interest payments occurred. On average, interest compromised about 5% of the purchase price, but the range was large, and the dataset included situations where loans amassed interest equivalent in value of up to 40% of the purchase price.

The median time to repayment was a year and a half, with some loans taking up to 8 years. 47% of loans missed their repayment date, and those repaying late took an additional 1.5 years on average. With longer loans, the interest rate experienced fluctuated prior to repayment. Interest rates for the LPF are set annually and varied between 4% and 7% annual interest within the time frame of this data set.

Purchase Price and Interest

A significant positive correlation between purchase price and interest across predicted and realized circumstances demonstrates that larger deals do bear a higher financial cost (Fig. 1). However, the correlation between the predicted purchase price and predicted interest is much higher than that between realized purchase and realized interest. When moving from the expected outcomes to realized outcomes, many occurrences may alter repayment schedule to explain this pattern. First, the principal of the loan may be lower than purchase price due to assistance from partners or funds in hand lowering the charge observed in the loan account. Interest accrued can be substantially lower than expected (sometimes zero) due to take-out plans or other funding materializing faster than expected. In contrast, interest may be higher than anticipated when funding plans fall through. The decreased goodness of fit in the realized scenario illustrates the decoupling of financial costs with purchase price as potential realities transpire. This variation highlights the importance of understanding determinants of loan performance.

GLMM

To determine correlates of loan performance, we tested the significance of predictors in a GLMM framework (Table 2.2). In the model explaining total interest accrued by a loan, a small number of variables show significant explanatory power. Purchase price is positively correlated with total interest accrued. Funds in-hand and pledged are both negatively correlated with total interest. These predictors are all indicative of the initial principal for the loan and so intuitively support these correlations with accrued interest. In addition, deals that have planned recreational use are less likely to accrue large amounts of interest. I also find that including state as a random effect produces a significant improvement of the model, showing a conditional R-squared value of 0.43 as compared to the marginal R-squared value of 0.18. This improvement indicates that there may be unexplained variation among state chapters that impacts loan performance. This difference among state chapters persists beyond the characteristics of TNC state chapters for which I already control, including average expenditure and income.

In the model explaining missed repayment deadlines, no variables show significance and little variation is explained (R-squared .10). In the model predicting unanticipated interest, only a single variable, state chapter expenditure, shows a slight negative correlation. This may indicate that a history of land acquisition projects and experience helps to lower the likelihood of unanticipated interest. Still, little variation in this performance metric is explained by the model (R-squared .03).

Prioritization

The two alternate priority rankings, with and without interest costs, are highly similar with Spearman ρ value of .99. Though there were no large movements within the rankings, 75% of projects changed their ranking placement. On average, deals shifted up or down in rank by 2 spots. This demonstrates that financial costs are large enough to change the ranking of projects in an ROI framework and had TNC not had the funding to support all of these projects, likely would have impacted the "marginal deal" chosen for protection. This remains true with use of either predicted or realized interest amounts.

Discussion

In this paper, I analyzed land acquisition deals financed through a major land trust's internal revolving fund to take an important first step in evaluating costs and risks of loans for conservation action. I show that costs associated with loan financing can be substantial in size, adding up to 40% of the purchase price to the total investment on the project in extreme cases. I also show that more expensive projects give rise to higher loan costs. Borrowing also carries an opportunity cost that may grow with time to repayment.

There is a clear benefit to the act of borrowing to enable purchase of a targeted parcel, namely that the land is protected and not developed; however, monetary resources may be unavailable to an organization or the lending agency to pursue other projects that crop up in the interim. If a loan drags out past an anticipated repayment, as almost half of the loans do in my dataset, this inflicts an unanticipated opportunity cost on the borrower and lender.

The dataset analyzed here demonstrates a relatively high rate of loans extending beyond their predicted repayment date. Nevertheless, loans tended to overpredict their total interest payments. This may indicate a poor ability to accurately predict financial outcomes, or a low level of discipline in maintaining strict repayment schedules.

Here I have limited my analysis to an internal revolving loan fund. While this helps to provide consistency across the dataset, this may limit my ability to generalize my results to external lending scenarios. Conversations with practitioners and writings on the subject indicate that loans for conservation from external organizations exhibit very low default rates (Clark 2007, & *pers comm:* Amundsen). This may indicate a higher aversion to risk of default under an external loan structure, and likewise my study may show that internal loans provide more cushioning and flexibility regarding loan repayment. This flexibility in turn may provide a structure under which other preferences are revealed. For instance, with less danger of penalties for poor loan performance, the financial costs of taking on debt may better reflect perceived opportunity costs. Estimations, such as this, may inform broader conservation planning and decisions by other land trusts.

In addition to showing that loans deviate from expected repayment paths, I find that it is difficult to predict which loans will deviate in terms of late repayment or unanticipated costs. Though total interest accrued is highly correlated to the purchase price and funds already dedicated to the project, variation in these other loan performance metrics was not explained well by characteristics of the deal itself nor by the borrowing chapter. I also performed sensitivity tests by adding other factors into this basic model, including habitat type protected, partner organization type, and a recession year dummy indicator. None of these inclusions improved significantly upon the performance of the model presented in the main text.

Part of the fixed risk of loan-taking is the potential for the inability to repay along the expected repayment path. This risk should be mitigated with the assignment of an appropriate interest rate. In my analysis, the inability to predict deviations from the planned repayment paths suggests that the risk is evenly distributed across loans of varying characteristics. For an organization like TNC to conduct financial planning, it needs to be able to project in-flows and out-flows associated with these loans. That is made more difficult if state chapters often break with their repayment plans. The departure from repayment expectations may indicate that the incentive structures are not set up correctly, meaning interest rates may be too low or penalties may need to aid enforcement of repayment schedules.

As mentioned earlier, a major caveat of this study is the limited scope of focusing on internal revolving funds. The establishment of internal revolving funds is growing in popularity in the land trust community, although may not be feasible for the smallest land trusts. Conservation loans are offered across many different organization types and extension work to investigate costs, risks and benefits of other loan structures is crucial to furthering our understanding of this topic. Similar models of financing for conservation are being replicated in other sectors. Financing is combined with philanthropy in Impact Investing, where a gift is offered by a loaning entity that absorbs more risk with a lower expected return (Hamrick 2016). Similarly, financing conservation through Program Related Investments as a form of mission-oriented work is also growing in interest among foundations and other organizations managing large endowments.

An additional topic for extension work is the study of risk preferences of conservation non-profits through their pursuit of financing options. Although loans are a great tool for capacity building, they also change the financial structure of an organization (Bowman 2002). We should consider that the optimal debt to equity ratio may be lower in non-profits than for profit organizations (Bowman 2015). This may be reflective of a lower financial security, though conservation has been shown to be resilient through recessions (Larson 2014). Instead, this may demonstrate a risk preference of non-profits. This risk preference may also appear in choice of collateral for loans. Most land acquisition projects are reluctant to offer the property itself as collateral due to the motivation to conserve that property in its current state and unwillingness to see it developed. This adds an additional challenge for conservation organizations to find adequate collateral or letter of guarantee to securing external loan with low interest rates (Clark 2007).

Utilizing loans as a tool for financing conservation land acquisition is a widespread practice and critical to expanding capacity of non-profit land trust organizations. It is important to understand the inherent costs and risks associated with this mechanism as well as particular aspects of projects that predict these costs for the lending and borrowing organizations. I demonstrate the potential magnitude of loan-associated costs, but identify few characteristics that explain variation in loan performance. I believe further research, collaboration, and education can help expand the effective use of loans as a beneficial tool in land acquisition.

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Appendix 1: Tables

Table 2.1 Predictor variables

Hypothesized correlations with propensity to default and interest accumulation as well as summary statistics of deal and state chapter characteristics

	Predictor	***H***	***Unit***	***Rationale***	***Data Summary***
Deal Characteristics	**Purchase price**	**(+)**	Dollars	More expensive projects may be more difficult to repay	Min: 1 million Median: 2.4 million Max: 76 million
	Funds in hand	**(-)**	% of purchase price	Available funding is a factor actively used to assess loan applications. Funds in-hand and pledged are hypothesized by land trust contacts to be the factors of highest explanatory power (pers. comm: Hall & Amundsen).	Min: 0% Mean: 5% Max: 100%
	Funds pledged	**(-)**	% of purchase price		Min: 0% Mean: 3% Max: 200%
	Human land use, Recreational	**(-)**	1/0	These variables might be indicative of future revenue sources or outside interest in funding for a deal.	46% of deals
	Human land use, Extractive	**(-)**	1/0		29% of deals
	Number of partner organizations	**(-)**	count	A large number of involved partners may buffer the uncertainty in financing or may be indicative of a long running or complex deal, either of which may help to ensure timely repayment.	Min: 0 Median: 4 Max: 11
	Take-out plan	**(-)**	1/0	Take-out plans would indicate a large source of planned revenue a deal and therefore may decrease the likelihood of late repayment.	57% of deals had take-out

Table 2.1 Continued

	Predictor	*H*	*Unit*	*Rationale*	*Data Summary*
State	**State experience**	**(-)**	Total chapter expenditure 2000-2009 (dollars)	More experienced borrowers may have better loan performance.	Min: 30 million Median: 106 million Max: 489 million
	State fundraising	**(-)**	Total chapter fundraising 2000-2009 (dollars)	Higher regular income is associated with a lower risk borrower	Min: 14 million Median: 48 million Max: 138 million
	Random effect, **State**		categorical	Larson et al. shows some patterns that certain state chapters behave differently in terms of fundraising before or after deals. This indicates that state chapter culture may play a factor in financial strategies, and subsequently loan performance.	24 states; Median 6 loans per state

Table 2.2 Loan performance metrics

<table>
<tr><th>Loan Response Variable</th><th>Definition</th><th>Data Summary</th><th>Implications</th></tr>
<tr><td>Total Interest Accrued</td><td>Interest between start date and repayment date</td><td>Min: $ 0
Median: $104,136
Max: $ 12 million
17% of deals accrued no interest</td><td>Traits associated with greater interest, have higher overall costs. These traits should thus be carefully considered in the costs assessment phase of deal planning.</td></tr>
<tr><td>Amount of Unpredicted Interest</td><td>Total Interest - Predicted Interest</td><td>16% of deals under-predicted interest; of those, median additional interest accrued was $163,000</td><td rowspan="2">If traits show a relationship with missed predictions, then these traits may be associated with higher or lower risk and should be considered in a screening process. Deals with high risk correlates may have augmented interest or some other contractual obligation. If no traits, including state chapter, shows a relationship, then risk of deviation has been spread evenly across deals indicating that all chapters and deals should be subject to the same rules.</td></tr>
<tr><td>Missed Predicted Repayment Date</td><td>Binary variable (1/0); Observed versus predicted repayment date</td><td>47% late; of those, median additional time was 1.5 years to repay</td></tr>
</table>

Table 2.3 Generalized linear mixed model results

(significance levels: '.' 0.1; '*' 0.05; '***' 0.0001)

	Total Interest			Missed Repayment		Unpredicted Interest		
Predictor	**Estimate**	**SD**		**Estimate**	**SD**	**Estimate**	**SD**	
***log* Purchase Price**	**1.538**	**0.356**	*****	-0.108	0.183	0.0003	0.010	
% of Price In Hand	**-4.997**	**2.007**	***	-0.849	1.044	0.018	0.057	
% of Price Pledged	**-1.732**	**0.790**	***	-0.155	0.416	0.005	0.023	
Take-out Plan	-0.125	0.656		-0.167	0.334	-0.014	0.018	
Total Number of Partner	-0.056	0.152		-0.043	0.082	0.001	0.004	
Land Use, Recreational	**-1.740**	**0.848**	***	-0.704	0.444	0.001	0.024	
Land Use, Extraction	-0.062	0.859		0.227	0.464	-0.022	0.025	
State Expenditure	-0.002	0.007		-0.002	0.002	**-0.0002**	**0.0001**	**.**
State Fundraising	-0.026	0.027		-0.001	0.008	0.0004	0.0004	
***Random Effect*, State**	**Var: 6.283**	**2.507**		Var: 0.000	0.000	Var: 0.114	0.338	
	Marginal R-sq: 0.177 Conditional R-sq: 0.429			Marginal R-sq: 0.07373 Conditional R-sqd: 0.105		Marginal R-sq: 0.0355 Conditional R-sq: 0.0355		

Table 2.4 Matching criteria for land acquisition deals.

To match a single project across TNC datasets (proposals and loan accounts) multiple criteria were used. All four criteria must be met for a positive match. In rare occurrences, an exact match could be made with an account number listed in the abstract. This instance outweighs a lack of other matching criteria.

Characteristic	Match Criteria
State Name	Exact name match
Property Name	Partial name match
Purchase Amount	Purchase observed in account must be within 20% of purchase price stated in proposal
Purchase Date	Date of observed purchase in account must be within 3 months of potential closing date listed in abstract

Appendix 2: Figures

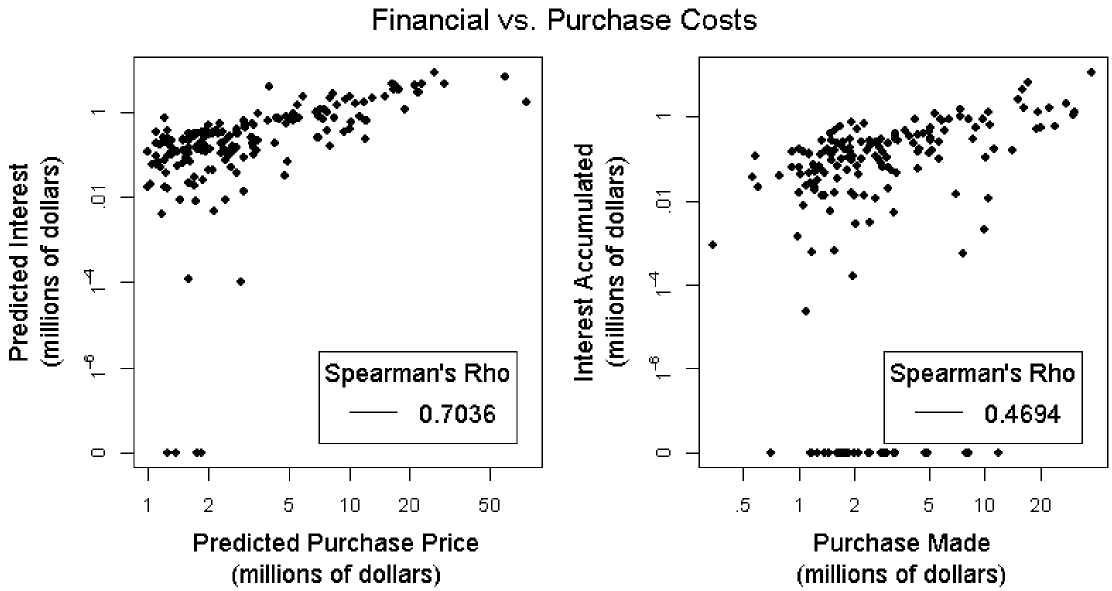

Figure 2.1 Correlation between purchase price and interest.

Left panel: predicted values; Right panel: realized values. Both predicted and realized before and after pictures show significant correlations ($p << 0.01$), but demonstrate that reality rarely follows predictions and the correlation becomes uncoupled as chance events add variance to the system.

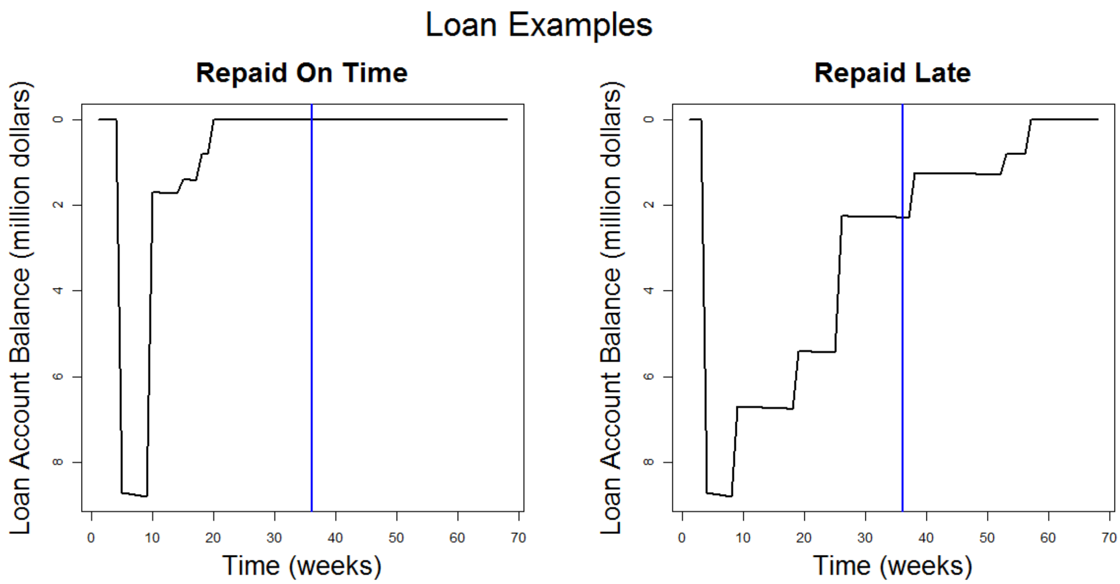

Figure 2.2 Example time series of cost centers for one TNC deal.

Blue line marks the estimated repayment date. Realized repayment days is marked when account regains a near-zero balance (defined as 0.1% of the purchase price).

CHAPTER 3

THE LANSCAPE OF CONSERVATION FUNRAISING

A version of this chapter was submitted for publication by R. Fovargue, J. Harris, M. Fisher, and P. Armsworth:

Fovargue, RE, M Fisher, J Harris, PA Armsworth. "The Landscape of Conservation Philanthropy". *Conservation Letters*.

MF & JH produced key data sets, provided input into analysis, and helped with final revisions of the manuscript. RF & PA both contributed to the study design, data analysis and interpretation, as well as revision of the article. RF was primarily responsible for data compilation and analysis and writing first drafts of the article.

Abstract

Finding ways to increase financial support is critical to conservation efforts. I use conservation fundraising data that are unprecedented in their resolution to reveal spatial patterns in philanthropic giving. These data describe giving to a major land protection organization in the US. I can explain around 40% of the variation in the propensity to give and overall value of gifts based on sociodemographic and other predictors. For example, education level has greater predictive capacity than income, political views and other factors often considered important. I also quantify the relationship between the amount of effort devoted to fund-raising and donations received. I illustrate how a conservation organization could use my approach to inform efforts aimed at increasing philanthropic giving and provide an example that, if followed, offers a potential increase of almost 40% or USD $200 million in fundraising revenue for the focal conservation organization.

Introduction

Private conservation organizations play a critical role in conserving new protected areas. In the U.S. alone, private land trusts have protected over 23 million hectares by buying land or establishing easements (Chang 2016). But land protection is expensive (Davies et al. 2010) and funding for conservation often falls far short of what is needed to achieve protection goals (Bruner et al. 2001; Merenlender et al. 2004; McCarthy et al. 2012) By better understanding philanthropic giving to conservation, organizations may be able to identify ways to increase funding support, allowing more on-the-ground conservation to proceed.

Philanthropic gifts constitute a vital source of funding for conservation (Clark 2007). Gifts typically make up 50-95% of revenue to U.S. land trusts, my focus in this study (Guidestar 2016). Spatial gradients in conservation philanthropy appear pronounced but have only been coarsely described (e.g. state level - Larson et al. 2016, country level – Halpern et al. 2006) greatly limiting inference about what predicts giving. Despite the obvious link between funding and on-the-ground actions, the conservation literature has largely focused on where to invest available funds and largely ignored where those funds originate (Withey et al. 2012; Groves & Game 2016). Some information about giving is available from non-spatial stated preference studies (Pate & Loomis 1997; Yen et al. 1997; Greenspan et al. 2012), but no previous work has examined large-scale, finely resolved patterns of realized giving to conservation organizations.

Understanding the landscape of donations is important for two reasons. First, understanding correlates of propensity to donate allows for improved spatial targeting of fundraising efforts, potentially increasing resources for additional conservation. Fundraising requires a substantial investment of staff time and other resources. Thus, the fundraiser's problem is conceptually identical to a conservation planning problem where limited funds for conservation concentrate actions on places of highest return (Margules & Pressey 2000; Withey et al 2012). These two optimization problems are connected through the conservation budget which can be augmented by strategic fundraising and subsequently expands the set of possible conservation actions through a relaxed budget constraint. Effectively directing fundraising effort to locations that promise the greatest return in terms of future giving is therefore important. Second, conservation actions can be constrained by funding origin because many gifts are restricted to be spent on particular regions or projects (Ando & Shah 2010; Larson et al. 2016). Accounting for these funding constraints is an important step in the implementation of proposed conservation plans (Carter et al.

2014). Identifying the landscape of conservation fundraising would help define the impact of this constraint.

In this paper, I identify how sociodemographic and other characteristics of an area explain observed giving patterns to a large U.S. land trust. Based on writings on general giving patterns to nonprofits I identify candidate predictor variables that may explain variation in giving to conservation among US ZIP codes. I first identify what predicts whether a ZIP code has provided at least one donation. Then, conditional on a gift having been made, I identify what explains variation in the overall financial value of gifts. With my novel dataset, I provide an unrivalled picture of spatial variation in private conservation donations and highlight the benefits of strategic fundraising behavior to maximize future giving.

Methods

Case Study

I focus on patterns of giving from inside the contiguous US to The Nature Conservancy (TNC), a private land trust. TNC has a 60-year history of land preservation and currently earns over $500 million in annual contributions (Birchard 2005; Guidestar 2016). TNC provided data on giving to the organization from donors that they class as "middle tier donors"; these are individuals who have given annually between $1000 and $100,000 to the organization. To maintain sufficient anonymity, I am not able to include gifts from the largest donors. While acknowledging that these top donations are important to fundraising for extensive non-profits, the range in size of middle tier gifts readily encompasses the largest donors to some smaller land trusts. Further, this sampling group allows for adequate coverage on a national scale to permit rich statistical analyses and spans important axes of variation in factors potentially associated with giving under scope of this paper. So, although I use a censored giving dataset, this rare access to real philanthropy data is a significant first step in quantifying spatial patterns of conservation giving. TNC provided donation data for 5 post-recession years (2009-2014). Donations are spatially aggregated to Zip Code Tabulation Areas - referred to throughout as ZIP codes - defined by the 2010 census (see Supplemental Materials 1 for more details on this spatial unit). ZIP codes contain on average 3000 residents.

Data

I identified a list of potential predictors of giving based on conversations with land trust practitioners and ideas drawn from general nonprofit writings. Prior studies suggest determinants of philanthropy can be grouped into several categories: the ability of an individual to donate money, an awareness of the organization, and a value set that aligns with the cause (Sargeant 1999; Bekkers & Wiepking 2011). I identify demographic factors at a ZIP code level that align with these suggested determinants of giving.

First, age and income have been identified as factors that increase ability to donate. Wealth provides potential for larger gifts and older individuals have been shown to give more than younger counterparts (Mount 1996). Consequently, I include percent of population of retirement age, median income and percent of households in poverty as predictors in my study.

Second, awareness of an organization may be estimated through fundraising intensity in an area or by geographic closeness to organizational activities – in this case nearness to protected lands. These factors are represented in my model by fundraising effort and amount of protected land within a day-trip distance of the ZIP code (Cordell et al. 2013). Communication intensity and style is important to donors (Sargeant et al. 2006), so TNC provided a history of contact instances (calls, letters, emails) for a large portion of donors in the data set. This list was aggregated to ZIP code to allow me to account for this important interaction.

Third, several demographics describe tendencies toward pro-environmental values. Studies show that higher educational level and left-leaning political beliefs may influence an individual's inclination to support a conservation organization through giving of money or time (Ryan et al. 2001; Chen et al. 2011; Greenspan et al. 2012). Thus, I include as predictors percent of adults earning a bachelor's degree and percent voting Democrat in the 2012 presidential election as proxies for educational level and political leanings.

Table 3.1 gives lists the full set of predictors, several of which I transformed prior to model fitting to allow for a more balanced design. Transformations and sources for datasets are detailed in Table 3.3.

Analysis

I use a Generalized Linear Model (GLM) to explain variation in donations at a ZIP code level. One limitation of the data is that TNC were only able to provide fundraising effort information for ZIP codes that provided donations. Given this, I split my analysis into two questions: which predictors explain the presence of a donation in a ZIP? Which predictors explain the magnitude of total donations observed in the 15% of ZIP codes with at least one gift? To answer the first question (presence-absence of gifts), I used a binomial model that does not presume knowledge of fundraising effort (Model 1). To answer the second, I focus on the 5215 ZIP codes where gifts were received and for which I had fundraising effort data. This time I used a GLM with a negative binomial form to predict the total gift amount in dollars from a ZIP code over the 5-year time period (Model 2). The basic model specifications are:

Model 1: $logit\left(E(Y_i^1 \middle| X_i^1\right) \sim \beta_0^1 + \beta_X^1 * X_i^1$

Model 2: $log\left(E(Y_i^2 \middle| X_i^2\right) \sim \beta_0^2 + \beta_X^2 * X_i^2 + \beta_{effort}^2 * X_{effort,i}^2$

Here, β indicates the coefficients to be estimated in the GLM, and X is a vector of the predictors listed in Table 2.1. Y^1 is the propensity of a donation, whereas Y^2 represents the total dollars donated. Subscript i indicates the ZIP code. Superscripts 1 and 2 respectively designate the full national set or donating subset of ZIP codes for each model. I estimate the full models and test the beta coefficients for significance from zero. I examined variance inflation factors, confirming any collinearity among predictors was within acceptable levels to proceed. After the estimation, I checked model residuals for spatial autocorrelation. Model 1 residuals showed a small amount of spatial autocorrelation over a 40-km lag, but re-estimating a regression model including spatially lagged error terms changed the results little. Therefore, I present the simpler non-spatial model in the main text and provide the spatial version in Supplemental materials 2. Finally, I present examples based on an analysis of model residuals to show how my work can inform spatial fundraising efforts.

Results

My database of conservation donations included over $350 million (2010 USD) and 160,000 individual gifts. The size of gifts is skewed as is typical of donation data (Yandow 2016). The top 50 ZIP codes each contributed a million dollars or more over these 5 years, while most gave much smaller amounts with 50% donating $11,000 or less over the same time span. Also, gifts were given in only 15% of US ZIP codes. An interpolated map of donations highlights both the location and magnitude of giving (Fig 3.1). Most donations are made by coastal urban populations with a few central U.S. metropolitan areas like Chicago, Denver, and Minneapolis also contributing large sums.

Generalized Linear Model

I first examined what factors were associated with whether or not a gift was made. Population, average income, education, politics, and existing conservation coefficients conform with my hypotheses (Model 1, Table 3.1 & 3.2). For example, ZIP codes with larger average income and more local protected areas were more likely to have given gifts. Conversely, population density, % in poverty, % households with dependents, and % of retirement age exhibit unexpected or no effect. I can illustrate more clearly which predictors show the greatest association with the presence of donations by standardizing the predictors and working in standard deviation units. Total population size and educational attainment appear to be the most influential predictors (Fig 3.2). For example, ZIP codes in which an additional 10% of adults hold bachelors' degree are twice as likely to provide a donation.

Of those ZIP codes that donated money, I sought to explain variation in the total amount given. An important component in Model 2 is the estimate of how much effort TNC devoted to soliciting donations in each location. Fundraising effort had the greatest ability to explain variation in the total amounts being given. Five times the fund-raising effort in a ZIP code known to give donations (a standard deviation increase in log(Effort)) demonstrated a doubling of the total dollars received. The next most influential predictor for size of gift is educational attainment (Fig. 3.2). For a standard deviation increase in educational attainment (about 18% of the adult population) in the region, the dollars received almost doubles. Additionally, % population of retirement age, and existing conservation exhibit coefficient estimates aligning with my hypotheses (Model 2, Table 3.1 & 3.2). However, total population size in a ZIP code, population density, average income, % poverty, political leaning, and % households with dependents either had no effect or an effect that was contrary to my hypotheses.

Using Model Residuals to Inform Actions

By comparing predicted donations from both models against the observed data, I can identify places that are donating more or less money than would be expected given local conditions. This information would allow an organization to direct fund-raising effort or to examine whether there are methods and approaches being used by staff soliciting donations from top-giving locations that could be replicated by staff working in locations currently giving less than would be expected.

For example, I can identify locations that have a high probability of donating but have not done so with Model 1. I estimate 4560 ZIP codes have a high propensity to give and that no donations were received from 26% of these ZIP codes (Table 3.4). These locations provide prime areas for investigation by TNC to consider reasons for the lack of donor activity and perhaps to target for additional fundraising effort. Were these ZIP codes to start giving at a comparative rate as currently donating ZIPs, donations would increase by 22%.

Likewise, residuals of Model 2 allow me to identify areas underperforming in total donations received from among those ZIP codes that are giving. Performance here is defined by the difference between predicted dollar amounts given a ZIP codes characteristics and the realized donations from that area. ZIP codes performing well may provide templates of success while those showing lower than expected donations may be places to review current donor relations and possibly shift fundraising strategies. If donations from the lowest performing 200 ZIP codes were elevated to predicted levels, this would increase the total revenue observed in the dataset by a further 15%.

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Discussion

By examining 160,000 donations to a private land trust, we reveal how sociodemographic and other factors explain philanthropic giving to conservation and illustrate methods that could be used to unlock additional conservation funding. Our results highlight characteristics of a U.S. ZIP code that correlate with the occurrence and size of donations for land preservation. Three predictors rise to the top as demonstrating particularly strong explanatory power of donations. The strongest predictor of the occurrence of a gift is simply total population in that area. Although intuitive, this is an important piece of knowledge. This shows that giving behavior is not overwhelmingly from one area or group, but is proportional to the population within a ZIP code. Thinking about this in another way, one can expect that regardless of where you are fundraising, a certain percent of the population are potential donors at this level. In terms of the size of a donation, the strongest correlate is fundraising effort. The more instances of contact The Nature Conservancy had in an area, the larger donations from that area were likely to be. It is tempting to assume that more contact leads to more donations, but it is also likely that TNC contacted people more frequently who had already shown high giving propensity in the past. Regardless of directionality, there is a strong relationship between contact with donors and size of donation received. Confirming this pattern with empirical support should encourage organizations to build their stewardship capacity. Finally, the amount of college education in an area was a strong predictor in both models and fuels the hypothesis that education leads to pro-environmental attitudes (Dietz 1998; Greenspan 2012).

Model estimates supported our hypotheses on several regional characteristics. Donations to private land protection correlates with areas exhibiting larger proportions of retirement age individuals and the existence of other local protected areas. Previous literature has claimed that age is a key predictor of giving (Mount 1996). Our results support this, with larger donations arising out of areas with greater numbers of older citizens. This pattern may hold especially true for our dataset, because older individuals may have increased their level of giving to TNC overtime through stewardship interaction and become a middle tier donor, therefore visible in our dataset. Existing conservation lands show a positive relationship with donations. Although it appears that propensity to give and total size of gifts have opposing relationships with protected areas, if examining the parabolic curve determine by the estimated coefficients across the relevant sample space, both models in fact show an overall positive trend. However, it remains unverified whether exposure to conservation increases the propensity to give, or conversely, that areas where funding is readily available implement more local protection.

Surprisingly, several commonly held beliefs about giving correlates proved unimportant or contrary to established hypotheses. For instance, wealth negatively correlated with donation level, while poverty levels in a region was positively correlated with it. This challenges literature stating that money availability generally leads to more donations (Mount 1996) and suggests new hypotheses about potential giving to conservation from areas of high wealth heterogeneity. Additionally, giving negatively correlated with households with young dependents despite suppositions that families with children are more likely to be interested in conservation work (Bamberg 2003). This pattern may be indicative of an ‘available funds’ problem, and that young families are more likely to be giving at a low level, which is not visible in this data set. Appealing to young families still may be a good way to increase membership and start critical stewardship relationships with individuals that will give at higher levels later in life (Zaradic et al. 2009).

The most important contribution of studies like mine is to help increase levels of giving to conservation causes. Earlier I outlined two examples of possible increases in fundraising using residuals of the fitted models. Taken together, the effect of encouraging giving where preconditions are right but gifts have not been forthcoming and boosting giving from underperforming regions show a potential increase of almost 40%. An obvious extension to this work is to confirm that these patterns observed with middle tier donations continue to hold when considering the smallest and largest donors or other kinds of gifts. One might also consider that monetary donations are not the only way to support private conservation (Clark 2007; Armsworth et al, 2013). It would be important to look at patterns of land donation or volunteerism as a form of giving to land trusts. These other strategies for supporting land conservation may or may not follow the same demographic and spatial patterns. In addition to revealing current areas to shift fundraising efforts, an improved understanding of donation correlates with a dynamic view could assist an organization in finding the next place to look. For example, rapidly gentrifying areas are characterized by higher levels of poverty, while experiencing an influx of degree holding individuals (both correlates of donations). Demographic shifts such as this can happen in a matter of years and would signal a source of potential donors for targeting in a capital campaign (Freeman & Braconi 2004; Kahn 2007).

Further consideration on the dynamic context of fundraising brings about the possibility of optimizing a land trust's actions across the landscape. Analogous to spatial conservation planning (Margules & Pressey 2000; Groves & Game 2016), fundraising should be concentrated in places of highest expected return. In the statistical model presented, only two predictors of donations are controllable from the point of view of a land trust: fundraising and land protection in a region. The location and intensity of these actions on the landscape could be regarded as a joint optimization problem where both fundraising and conservation actions are placed simultaneously to maximize conservation outcomes, with the budget for both being the result of fundraising. Though my results indicate a positive correlation of both factors with donations, I do not yet establish the direction of these relationships (e.g., does fund-raising effort lead to increased giving or are TNC allocating more effort to locations known to have given more in the past?). While my results provide an important first step, extending this work with a careful examination of lags (see Larson et al. 2016) or instrumental variable approach (Angrist et al. 1996) would help parse out the direction of such relationships with controllable factors to more carefully consider decisions of fundraising intensity and land protection in this larger optimization framework. Another obvious extension would be to repeat similar analyses for other organizations, including smaller conservation organizations with quite different business models.

Conservation science has developed a wide array of tools and methods to aid prioritization of locations for protection. However, there are many allocation problems inside the regular operations of conservation organizations for which advances could be made if more scientific effort was shifted toward these broader aspects of land protection practice. To illustrate, I focused on fundraising as an enabling factor of conservation and analyzed patterns of over $350 million of giving to a nonprofit land trust. This type of research can assist organizations to spot regions receiving more or less donations than expected and redirect fundraising strategies accordingly. Ultimately, taking advantage of novel mechanisms to increase financial resources for land trusts is critical for reaching extensive protection targets.

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Appendix 1: Tables

Table3.1 Predictors of donation presence and total size.

Predictors of donation presence and total size. Hypotheses gathered from past literature and conversations with conservation practitioners.

Category	Metric	Beta Hypothesis		Posed Rationale
		Model 1	Model 2	
Population	Total population in ZIP code	+	+	Larger populations have more individuals to donate
Population	Population density (per ha)	+	+	Population density proxy for urban which is a strong demographic signal
Wealth	Median income	+	+	High levels of wealth indicate more expendable income and a higher likelihood of donating
Wealth	% Households below poverty line	-	-	Inverse of wealth
Education	% Completed bachelor's degree	+	+	Greater educational attainment is associated with environmental concern and likely to support conservation organizations
Politics	% Voted Democrat in 2012	+	+	Liberal politics is associated with environmental concern and likely to support conservation organizations
Household Structure	% Households with young dependents	+	+	Individuals with children are concerned for the future environment, and are likely to donate to conservation organizations
Household Structure	% > 65 years old	+	+	Retired individuals more likely to donate with expendable income, legacy or estate donations

Table 3.1 Continued

Category	Metric	Beta Hypothesis		Posed Rationale
		Model 1	Model 2	
Existing Observable Conservation	Hectares of protected areas within 75-miles	+	+	Two-way interaction term included; Low levels of conservation may inspire charitable gifts for additional conservation actions; high levels of conservation may conversely give the idea that additional support is not needed, and lower the observed support;
Fundraising Effort	Total contacts with donors	NA	+	Contact moments with donors leads to and is led by donations

Table 3.2 Generalized linear model results.

Generalized Linear Model results. Coefficients are from model estimation with raw or log transformed predictor data. Each coefficient is tested for overlap with zero with z-test. (Significance codes: 0 '***' 0.001 '**' 0.01 '*')

	Model 1: Is there a donation? *Logistic Regression*			Model 2: How many dollars? *Negative Binomial Regression*		
Variable	**Coefficient Estimate**	**Standard Error**		**Coefficient Estimate**	**Standard Error**	
log Population	1.10	.024	***	-3.86×10^{-3}	.022	
log Pop Density	-.219	.015	***	-.080	.014	***
log Income	.259	.097	**	-.207	.105	*
log Poverty	.145	.039	***	.311	.053	***
Education	.0817	.0019	***	.0331	.0017	***
Politics	.788	.150	***	-.123	.145	
Dependents	-.0483	.0031	***	-.0179	.0028	***
Retirement	-.0022	.0025		4.94×10^{-3}	.0022	*
sqrt PAs	1.03×10^{-3}	2.11×10^{-3}	***	-2.50×10^{-4}	1.98×10^{-4}	
sqrt PAs²	-3.14×10^{-7}	1.47×10^{-7}	*	3.99×10^{-7}	1.38×10^{-7}	**
log Effort	-	-	-	.386	.011	***
	Null deviance=29921 (28973 df) Residual deviance=18168 (28963 df)			Null deviance=10546 (5267 df) Residual deviance=6428 (5256 df)		

Table 3.3 Details of data sources for generalized linear models 1 & 2.

	Category	Metric	Year	Unit	Source
Response	**Donation Observation**	Presence of donation in ZIP	Aggregate 2009-2014	Binary	The Nature Conservancy
Response	**Donation Totals**	Aggregate donations in ZIP	Aggregate 2009-2014	Dollars	The Nature Conservancy
Predictors	**Population**	Total estimated population in ZIP	2011	No. individuals (log transform)	ACS 5-year estimate CIESIN Gridded Population of the World, V4[1]
		Population density; I used the average of two estimations. First estimation used the estimation of population and area from the American Community Survey (ACS) database. The second estimation used the average value within the ZIP from the CIESIN raster data.	2010	Population/hectare (log transform)	
	Wealth	Average earned income, per household	2011	Dollars (log transform)	ACS 5-year estimate
		% households below poverty	2011	% (log transform)	
	Education	% adults having earned a Bachelor's degree or higher	2011	%	ACS 5-year estimate
	Household Structure	% households with young dependents	2011	%	ACS 5-year estimate
		% over 65	2011	%	ACS 5-year estimate

Table 3.3 Continued

	Category	Metric	Year	Unit	Source
Predictors	**Politics**	% votes for Democratic Party 2012; County level data sourced from Associated Press reports and translated to ZIP through census relate table	2012	%	Associated Press reported outcomes[2] U.S. Census ZCTA/County relates
	Existing Observable Conservation	GAP protection level 1 & 2 in 75 mi buffer from centroid of ZIP; 75 mi buffer established from Forest Service estimates of median travel distance for day trip to natural areas.[3]	<2009	Km^2 (square root transform)	PAD-US[4]
	Fundraising effort	Total number of contact records with donors within an area in gift dataset	Aggregate 2009-2014	No. of Contacts (log transform)	The Nature Conservancy

[1]Center for International Earth Science Information Network - CIESIN - Columbia University. 2016. Gridded Population of the World, Version 4 (GPWv4): Population Density. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4NP22DQ. Accessed October 2016.

[2]https://www.theguardian.com/news/datablog/2012/nov/07/us-2012-election-county-results-download

[3]Cordell, H. K., C. J. Betz, S.J. Zarnoch. (2013) Recreation and protected lands resources in the United States: a technical document supporting the Forest Service 2010 RPA assessment.

[4]U.S. Geological Survey, Gap Analysis Program (GAP). May 2016. Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class.

Table 3.4 Contingency table of logistic model 1.

	Model Predicts Gift	**Model Predicts No Gift**	**Exhibited Totals**
Data Exhibits Gift	3388	2740	6128
Data Exhibits No Gift	1172	24259	25431
Predicted Totals	4560	26999	

Table 3.5 AutoLogistic model vs. non-spatial model coefficient estimate

In order to test results for unaccounted spatial autocorrelation, a Moran's I statistic was applied to the residual values from both models and was calculated across multiple possible interval distances. Model 2 showed no significant autocorrelation in residuals. Model 1 showed a small amount of remaining spatial autocorrelation in residuals over a 40km lag distance. To examine the possible impact of this on my results and interpretation, I use the autologistic() function in the R package ngspatial to run a version of Model 1 with spatially lagged error terms. The expanded model fit showed a 1.2% reduction in model deviance. However, all model coefficients remain of the same sign and of comparable size to the simpler model form (Table SI 3). Only average income is impacted by the more complicated model fit, with a coefficient less distinguishable from zero, lowering the significance and impact of this predictor. Income was already shown to be of little predictive value (left hand panel of Fig. 2, "median income") meaning my interpretations of explanatory characteristics remains unchanged.

Variable	**AutoLogistic Model Coefficient Estimates**	***Main Text GLM Coefficient Estimate***	
Population	1.162	*1.10*	***
Pop Density	-.2805	-*.219*	***
Income	.0423	*.259*	**
Poverty	.151	*.145*	***
Education	.0812	*.0817*	***
Politics	.400	*.788*	***
Dependents	-.0507	-*.0483*	***
Retirement	.0030	-*.0022*	
PAs	8.212×10^{-4}	1.03×10^{-3}	***
PAs^2	-1.150×10^{-7}	-3.14×10^{-7}	*
Eta (spatial parameter)	.06353		
	Residual Deviance: 18145	Residual Deviance: 18360	

Appendix 2: Figures

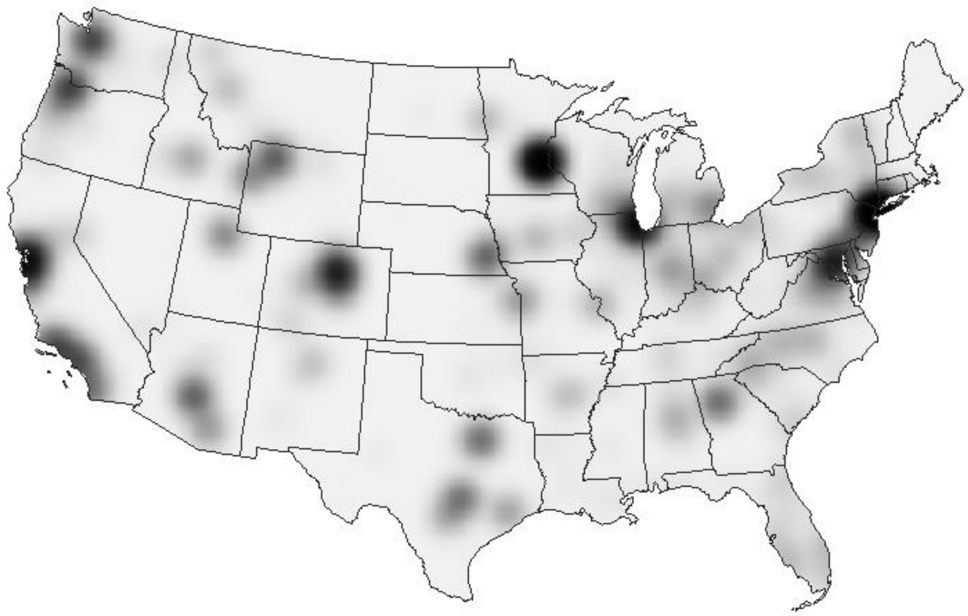

Figure 3.1 Interpolated heat map of continental U.S.

Dark regions represent donated dollars. Exhibits strong coastal and northern metropolitan pattern. Demonstrates both the general location of donative ZIP codes as well as the relative magnitude of gifts across regions. 15% of ZIP codes demonstrate a gift with range from one thousand to 14 million dollars over the period of data.

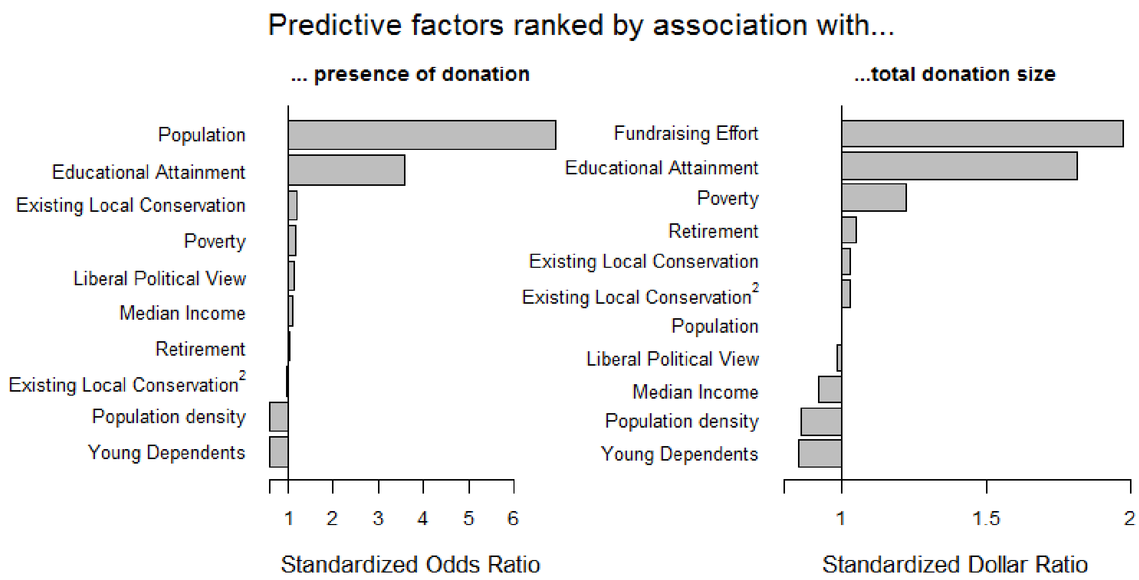

Figure 3.2 Standardized impact of regression variables on giving

Regression variables ranked by standardized impact on giving ($e^{\text{Estimated Coefficient}}$) for Model 1 (left panel) and Model 2 (right panel). Each bar represents the multiplicative change of a standard deviation increase in that predictor (1= no change). Model 1 shows how a standard deviation shift in each predictor variable impacts the odds of observing a donation in a ZIP code. E.g. All else being even, an area with 10% more households with young dependents (one standard deviation) is half as likely to have observed a donation. Model 2 shows relative possible impact of each predictor on the total dollars donated in a ZIP code. E.g. All else the same, an area with one standard deviation additional households in poverty is predicted to have 22% more dollars donated. This metric is log transformed, so in terms of raw data, one standard deviation shift approximates a doubling of households below poverty.

CONCLUSION

Establishment of protected areas is a multifaceted process that involves many linked decision points (Pressey & Bottrill 2008; Groves & Game 2016). My dissertation has informed various parts of this practice, from design through the financing of protected areas. In the introduction to my dissertation, I frame this process as three main questions under which my research falls:

1) Where to protect?

   In Chapter 1, I show that simple rules can incorporate connectivity into protected area design to better balance management goals (Fig 1.3, Table 1.1). I show the impact of spatial configuration on protected area success. Chapter 2 provides evidence that there is spatial variability (across TNC state chapters) in the expertise and use of loan financing for land protection (Table 2.2). This variation may result in differences in the effectiveness of protected area establishment in different regions. In Chapter 3, I illustrate fine-scale spatial variation in funding from philanthropic sources for conservation that may help to determine where new protection would be most feasible (Fig. 3.1). Each of these chapters helps to inform the "where" decision that conservation organizations face.

2) When to protect?

   In Chapter 2, I demonstrate that loan financing for land acquisition can be costly and that repayment patterns are variable and difficult to predict (Table 2.2). Regardless, loans are critical for enabling timely action for conservation opportunities during narrow temporal windows. This research helps to inform the decision of whether or not to pursue an opportunity by better establishing cost estimates for cost-benefit trade-off considerations by a conservation organization.

3) How to fund protection?

   Chapter 2 contributes to the literature on conservation non-profit financing as an option for rapid but short-term funding for a proposed acquisition project. Chapter 3 illustrates locations and demographics with a high propensity to donate to land conservation (Fig 3.2, Table 3.4). I demonstrate how the use of models and stewardship data can help target fundraising strategies toward areas of high potential support, thereby augmenting resources for conservation action.

Synthesis

Several themes emerge across the three research projects in this dissertation (Fig. C1), of which I highlight three in this Conclusion section: i) trade-offs in conservation decision making for practitioners; ii) flexibility or release from constraints for conservation decisions; and iii) the ability or need to scale up in terms of large protected areas to aid conservation goals.

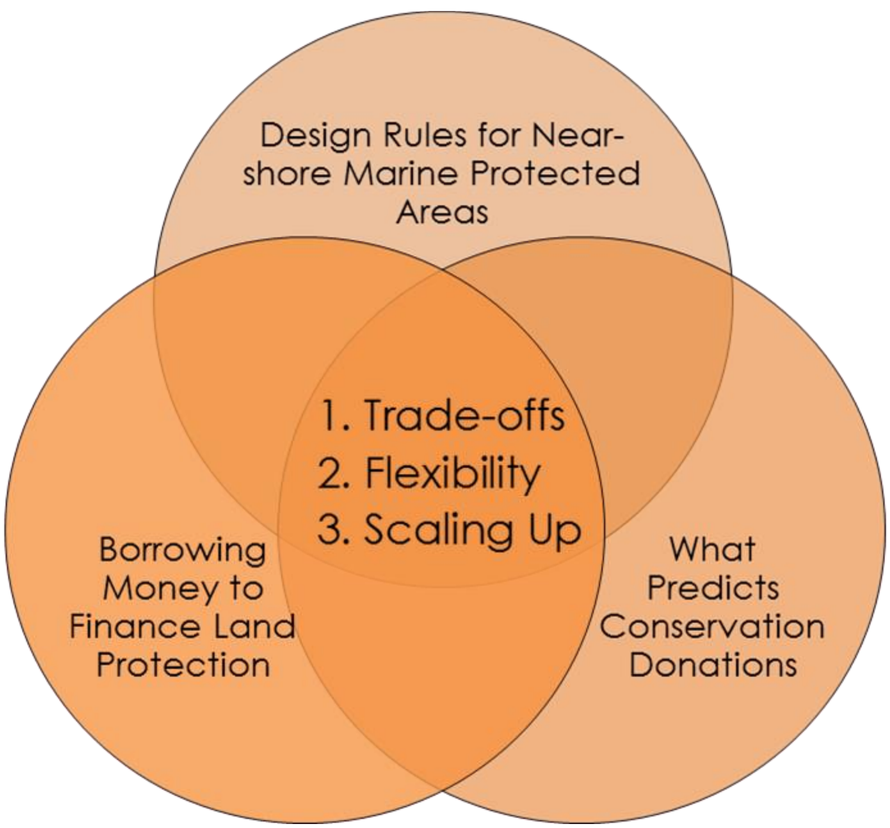

Figure C1. Intersection of themes across dissertation projects

Objective Trade-offs

The process of protected area establishment is riddled with trade-offs, where gaining a little more of one objective costs a little of another. If all objectives for a decision could be achieved easily by a single choice, no problem would exist. Two major categories of trade-offs that conservation organizations face are trade-offs in benefit functions given various on-the-ground conservation action choices, and trade-offs across options for investing resources inside the organization to best pursue organizational missions. My dissertation informs decision-making in both of these categories.

As part of their mission, conservation organizations may target multiple conflicting ecological benefits or struggle to balance conservation goals with human use goals (Polasky *et al.* 2008; Goldstein *et al.* 2012). This results in difficult decisions about resource investment into alternate regions, as well as about protected area shape and management (Groves & Game 2016). In Chapter 1, I look within an ecosystem type to explore one example of a design decision that trades offs between conservation and extractive use management goals. When establishing a near-shore marine protected area (MPA), alternative size and spacing configurations can support conservation or fishery goals to different extents (Botsford, Micheli & Hastings 2003). I demonstrate this trade-off in a highly-protected system where few large well-placed MPAs best support a wild fish population, whereas many small MPAs better support a large fishery catch. Alternatively, I highlight synergistic scenarios in over-fished systems with dispersal knowledgeable managers. This research illustrates how the size and spacing of segments composing the protected area affect the benefits received, even when the total area protected remains unchanged.

When zooming out to a multiregional scale, organizations face a trade-off between benefits across different regions, which are directly tied to threat of habitat conversion. On land, protection often requires ownership, so a large cost of protection is the price of the land. Land price is highly correlated with threat of development, (Naidoo *et al.* 2006) and thus purchasing decisions draw a trade-off between more land in a less threatened region versus less land in a more highly threatened region. This trade-off has been frequently discussed in the conservation literature (Ando & Shah 2010; Withey *et al.* 2012). However, missing in these past studies is a recognition that other factors also co-vary with land cost and threat that might ameliorate this trade-off. Specifically, in Chapter 3, I show that donations to conservation are also more likely in population dense areas. This means that it may be easier to fundraise for the land near cities, mitigating the higher cost. My insights into bridge loans in Chapter 2 also help inform a land trust on its ability to afford land acquisitions in expensive markets. By incorporating these considerations of fundraising and borrowing, my analysis adjusts the affordability of lands and lowers barrier for protecting in high-threat regions.

Trade-offs among options for investment and management of financial resources within the organization impose choices upon conservation non-profits that will impact performance. For example, land-protecting organizations often face a choice about whether to borrow money to pursue new protection projects. Inside of this decision, the classic risk – return trade-off emerges. With expensive projects, the potential for a high ecologic benefit exists, but if a loan is needed, financial risks arise. Risks can include loss of collateral or the property, loss of reputation or credit, and loss of other opportunities that arise while money is out of hand (Clark 2007). My research shows that more expensive projects rack up higher financial costs beyond purchase price. This means that when using debt financing to pursue large projects, conservation organizations take on more risk. Taking on some debt benefits the organization by leveraging money to help them grow (Bowman 2002). However, finding the right leverage balance is important, and many non-profits choose to minimize debt held by the organization (Young 2007; Bowman 2015). My research provides a first step towards better estimations of cost and risk burdens of conservation specific loans.

Organizations also face a trade-off in determining how to invest resources internally across mission-oriented or capacity-building work. In many land trust non-profits, mission-oriented work may include buying land or easements, whereas capacity building might be the creation of an endowment or revolving fund, or educational or fundraising campaigns (Bowman 2007; Duff *et al.* 2017). My research helps to inform conservation groups about the risk and costs associated with establishing internal revolving funds. My work also informs the decision about where to target expanded fundraising efforts. Areas of high potential for fundraising may trade off or overlap with areas of ecological benefits. Through this work, I also provide insight on improving the return on investment targeting of fundraising so that capacity-building investments are as efficient as possible.

An important future step to this research is identifying locations where synergies are possible between capacity-building and mission-growing work for conservation organizations. To attain this key piece of information, we would need to determine direct paths of causality between land protection work and realized donations, as well as resolve the willingness to pay of donors for conservation across varying distances. This link between on-the-ground actions and philanthropy would help to identify areas where investing in conservation can both bolster conservation goals and encourage donations, thereby increasing monetary resources for more protection.

Flexibility of Actions and Policy

A widely recognized principle in the context of protected area establishment is that organizations with greater flexibility regarding the placement of protected areas and management activity have a greater ability to optimize ecological benefits on the landscape (Kark *et al.* 2009; Micheli *et al.* 2013). Within my research, I explore constraints on flexibility of conservation actions through the dimensions of space and time.

First, I consider spatial flexibility of protected area establishment, i.e. an organization’s ability to place protection in whatever location and in whatever configuration best maximizes the desired ecological benefits. With my protected area design study in Chapter 1, I explore this in two dimensions: i) how performance of a protected area changes as more protection is added to the system; and ii) how performance changes as the protected areas are broken up into a greater number of unique areas. Breaking up protected area networks into many small protected sites can have the confounding factor of making enforcement more difficult, a realistic constraint on potential configurations. Regardless, my research shows the benefit side of added flexibility especially in scenarios where knowledge about dispersal is limited and configurations cannot be optimized. In this scenario, many small MPAs can create a more productive fishery.

Spatial positioning of protection can be constrained not only by enforcement considerations, but also by affordability. Conservation actions may be constrained by the local fundraising base, and therefore it is critical to understand the landscape for potential philanthropy to better prioritize conservation actions across space. In my research on fundraising, I provide a benchmark for fundraising for land trusts. From this they can identify areas that are most likely to support local conservation, and regions where it is more critical to find spatially flexible funds such as federal grants.

The pervasiveness of mismatches between project costs and on-hand funds highlights the importance of temporal flexibility of conservation actions for maximizing benefits on the landscape. The availability of funds, together with the timing of parcel availability, impose a major constraint on land protection decisions (Lennox *et al.* 2016). If funds are not readily available, then temporally flexible funding becomes a crucial option. Flexible funding includes borrowing money for acquisition and reselling the property later to a partner organization. By considering loans as an enabling factor of purchase, I explore how releasing this temporal constraint helps to build more opportunities for land trusts to pursue projects. Loans specifically allow an organization to use future income to buy a desired parcel on the land market right now.

My work on the flexibility of conservation actions also suggests several important next steps and extensions. For example, conservation loan financing, though applied in both terrestrial and marine settings, has been almost absent from the marine protection literature (but see Novriyanto *et al.* 2012; Bos, Pressey & Stoeckl 2015). A clear extension of my work in Chapter 2 is to examine the costs and risks associated with marine conservation loans. Another valuable area of extension work concerning conservation finance is to more clearly establish the frequency with which opportunities for acquisition arise on the market, and the quality of those opportunities. This would allow researchers to more clearly establish the benefit of and opportunity cost of land acquisition loans.

Scaling Up

Finally, throughout my research, I show that bigger can be better when it comes to establishing conservation protected areas, and provide insight into some enabling factors for growing the size of protected area projects.

It is well established in the literature that large protected areas maintain intactness and connectivity of ecosystems. Interior habitat in large terrestrial protected areas is valuable (Woodroffe 1998) and protected area size is a key trait for successful conservation outcomes in marine environments (Edgar *et al.* 2014). In my research, I provide a further example of the benefits of large MPAs. For spatially-managed reef systems, I illustrate that a large protected area can provide not only conservation benefits, but also natural resource extraction benefits in situations where optimal targeting is possible. Given the asymmetric dispersal of my population model, large well-placed MPAs can better grow a wild fish population while supplying the fishery through a spillover effect than numerous smaller MPAs.

In order to realize large-scale conservation areas, organizations need to take more collaborative actions and have access to financial tools that allow them to scale up. As my research highlights, by providing flexible financing options, revolving loan funds are perfect for enabling smaller organizations to pursue larger land acquisition deals for which they would otherwise not have ready funds. Organizations can also scale up their work by better appealing to donors. In my research, I provide examples of how efficient targeting of locations and individuals for fundraising purposes allow for augmentation of income for a land trust.

All three of my chapters demonstrate that optimizing for large scale conservation is a worthwhile pursuit. Future research could help to better target this objective by building joint optimization frameworks where decisions of fundraising, costs, threat and benefits are all connected on the landscape. In such a framework, actions would be simultaneously controlled for a large working budget and large protected areas. Organizational and conservation investment actions would impact both the budget and the protection portfolio. Subsequently, the land protection actions available would be constrained by the budget size.

Final Thoughts

My dissertation provides impactful research to aid conservation decision making that balances trade-offs and flexibility to enable large scale protected area design and implementation. Throughout my research, I have worked closely with practitioners and international decision science groups to ensure that my research has real-world relevance.

While developing this dissertation, I have invested time in engaging with and communicating my science and recommendations to relevant stakeholders. Early on, I gave seminars on the results of my reef model work to research groups in Australia, including coral reef scientists and fishery managers at the Institute for Marine and Antarctic studies in Tasmania. I have communicated the results of my collaborations with The Nature Conservancy not only with their staff, whom it directly informs, but also have engaged with members of the land trust community in conferences and meetings to better forge communication pathways to disseminate results. These types of valuable interactions between academic institutes and practitioners help to create novel opportunities for cutting edge research while contributing up-to-date science in support of real-world conservation solutions.

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